Intelligent Control and Management of Energy Storage Pilot Systems

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Energy Storage in Cyprus Workshop – Net technologies and challenges

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Outline

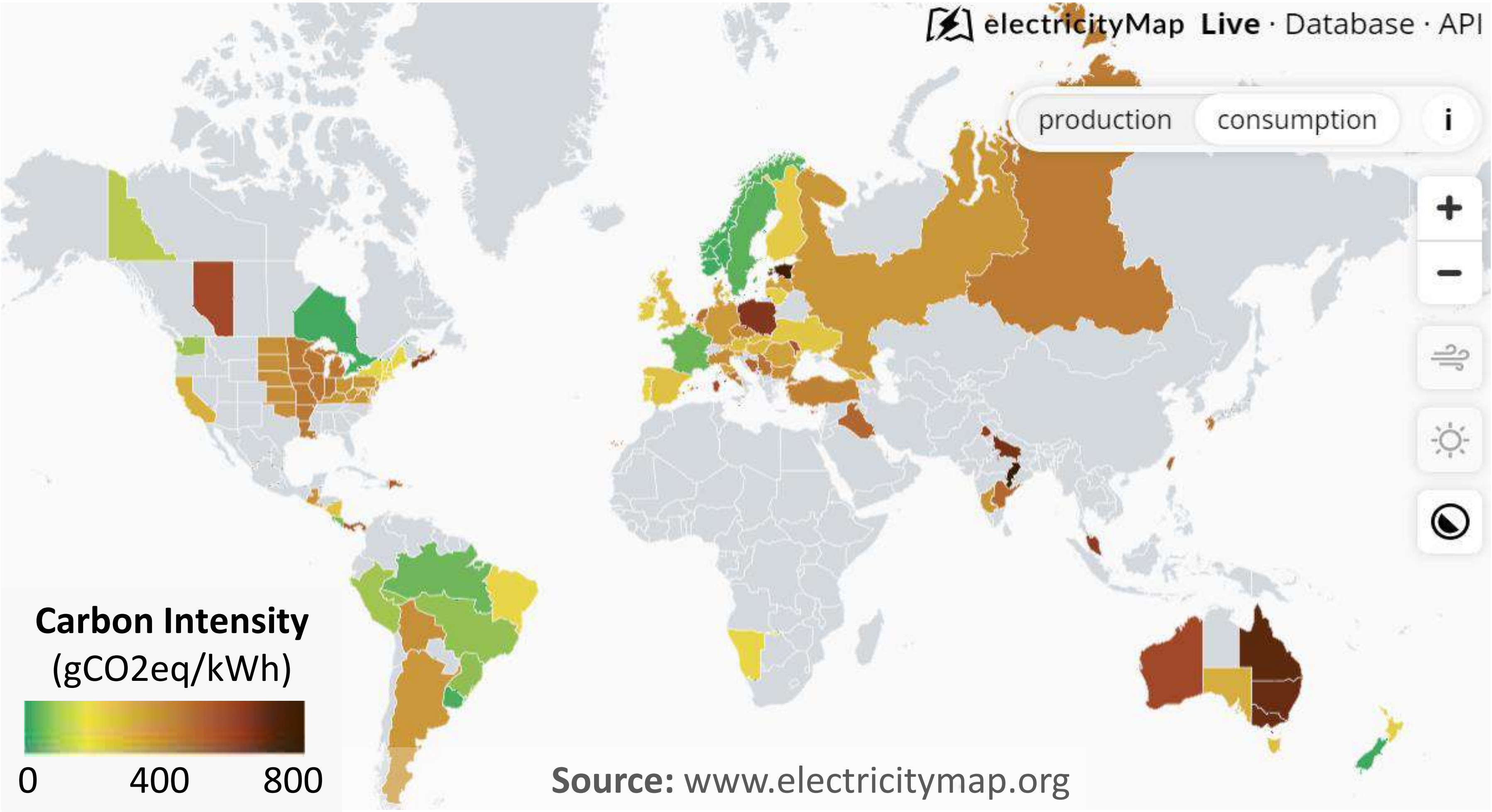
- **Introduction**
- **Energy storage pilots' development**
- **Intelligent control and management solutions for energy storage**
- **Conclusions**

Introduction

Problem

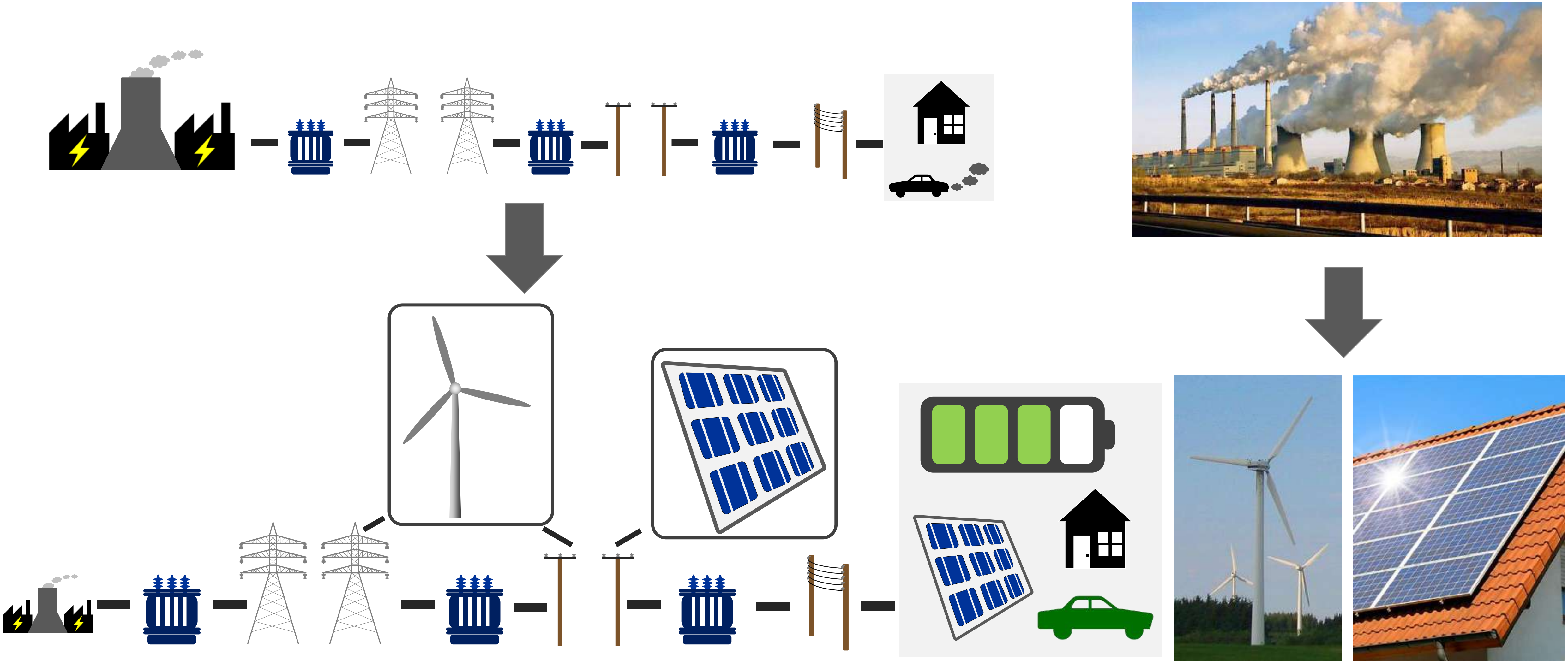
- **Traditional power systems (fossil fuels) are directly related to carbon dioxide emissions and global warming**

- Emissions per kWh



Motivation

- **Green, digital, intelligent and secure evolution of power systems**

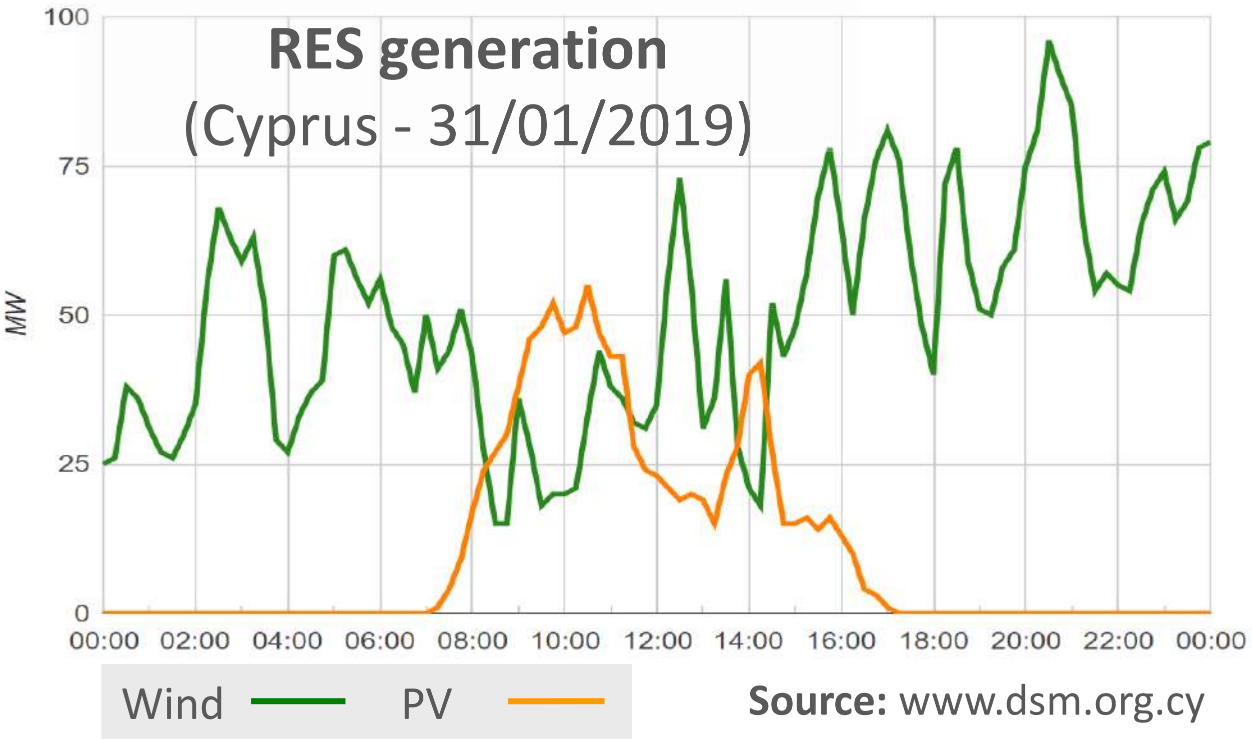


Challenges

- **The massive penetration and the unpredicted nature of Renewable Energy Sources (RES) imposes critical operational challenges:**

  - Stability problems - Inefficient operation - Power quality issues

- **Electrification of transportation and thermal sectors increases the demand**



Source: www.dsm.org.cy

Possible Solutions

- **There is a need to evolve power systems to ensure a sustainable, reliable, efficient and high-quality operation under the new circumstances**

Smart and intelligent non-wire solutions

Costly investments for traditional wire upgrades





Advanced Metering	Inverters, Storage	ICT, IoT	Intelligent Control

Upgrade substations, wires, cables

EMPOWER Solutions

1. **EMPOWER Platform - For enhancing the TSO management capabilities**
   - Upgrade the measuring infrastructure of 18 power substations with phasor measurement units for synchronized measurements every 20 ms
   - Integrate novel monitoring and control solutions for Cyprus power system

EMPOWER Solutions

2. Flexible Energy Storage Solutions (ESS) - For advancing RESs integration

- A holistic multi-level control framework for intelligent operation of ESS
- A universal architecture to integrate intelligent management-control algorithms
- Validation and demonstration of ESS in different pilots

Image credit: Stock

Energy Storage Pilots' Development

Energy Storage Pilots' Development

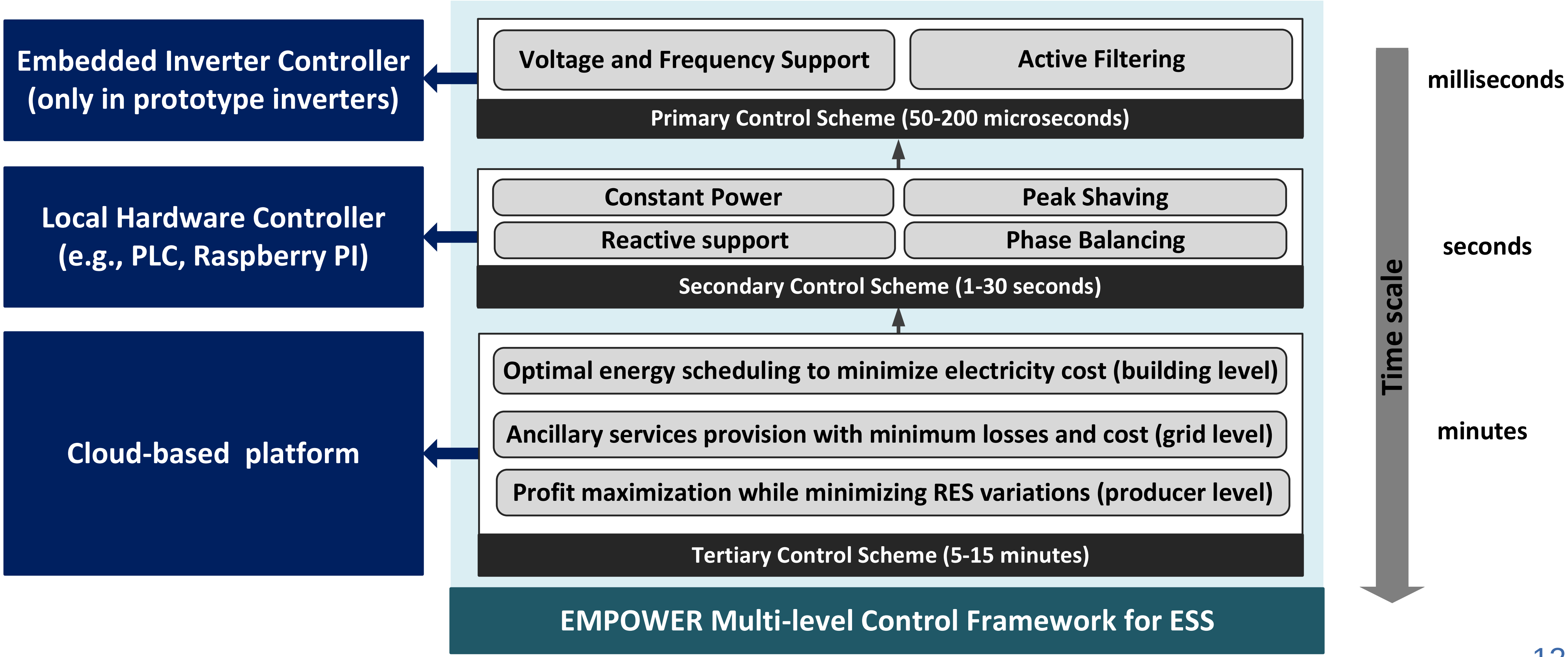
- **The development of pilot sites aims to demonstrate in real-life environment how intelligent control solutions for Energy Storage Systems (ESSs) can:**
  - advance the grid integration of RESs
  - enhance the competitiveness of green investments
  - maximize the allowable penetration limits for RESs

- **Three different energy storage pilots have been developed:**
  - At producer level
  - At grid-community level
  - At building level

- **A common platform architecture is applied in those pilots to integrate intelligent control and management schemes for the ESSs**

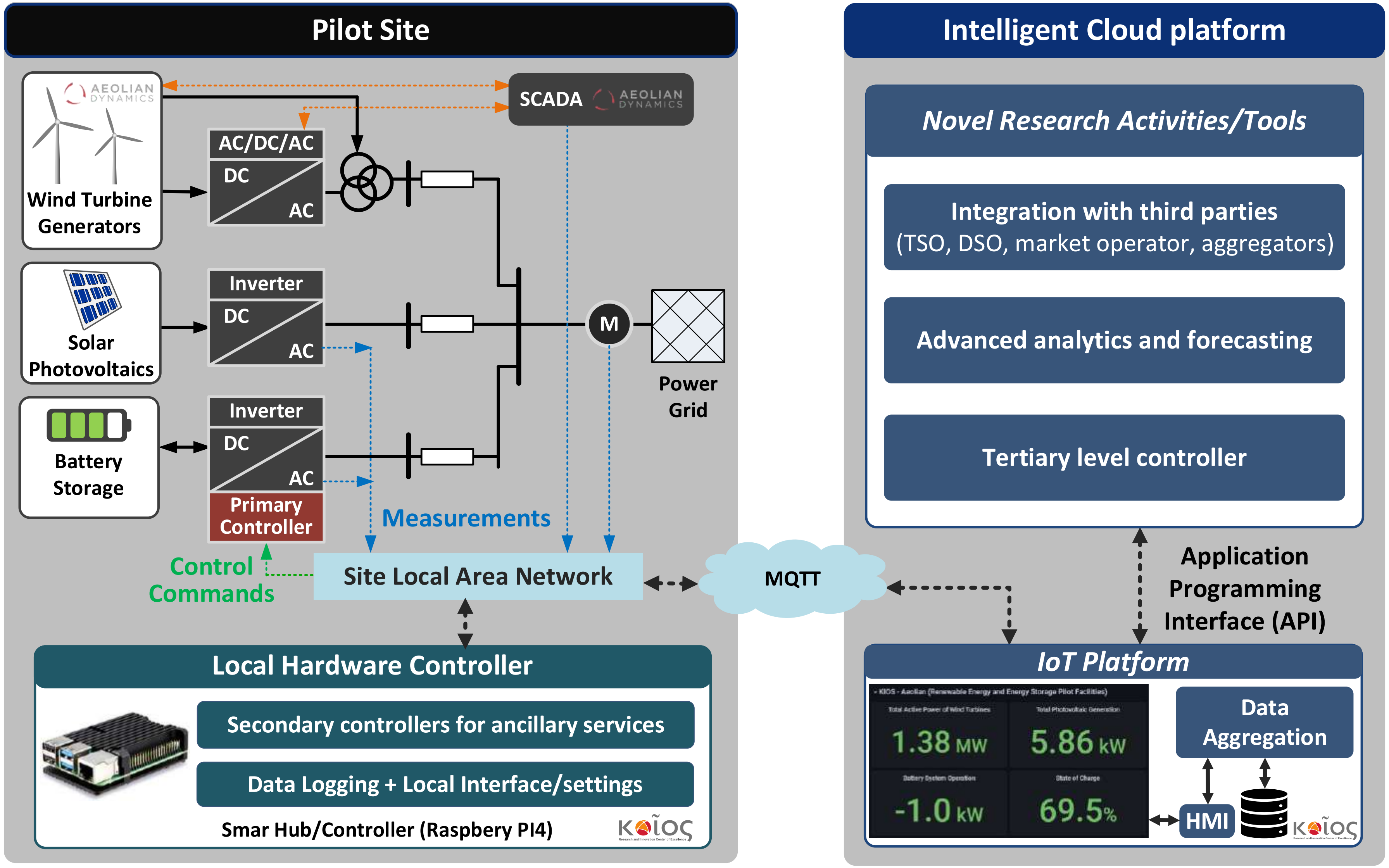
Energy Storage Pilots’ Development

- **A holistic multi-level and multi-functional control architecture**



Energy Storage Pilots' Development

- A common platform architecture to integrate intelligent control algorithms



Energy Storage Pilots' Development

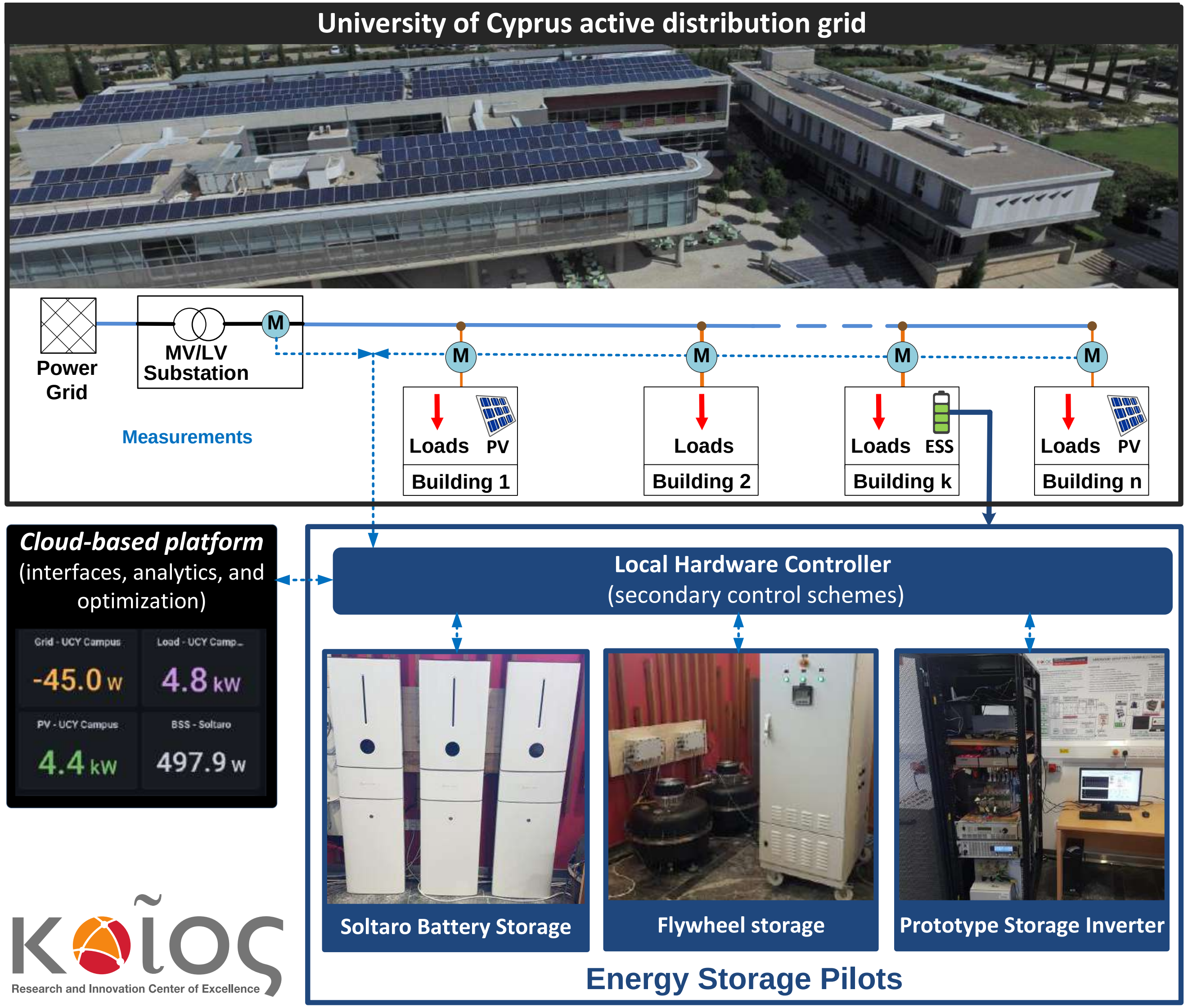
EMPOWER Pilot I - Energy Storage and RES – (producer level)


General / BSS - Aeolian
now-2d to now-1d EEST
30s
KIOS - Aeolian (Renewable Energy and Energy Storage Pilot Facilities)
Total Active Power of Wind Turbines
2.80 MW
Total Photovoltaic Generation
1.19 kW
Battery System Operation
4.43 kW
State of Charge
51.5%
Wind Turbines - Total Active Power
12 MW
10 MW
8 MW
6 MW
4 MW
2 MW
0 kW
18:00 21:00 00:00 03:00 06:00 09:00 12:00 15:00
Pwind_total
Photovoltaic - Total Active Power
8 kW
7 kW
6 kW
5 kW
4 kW
3 kW
2 kW
1 kW
0 W
18:00 21:00 00:00 03:00 06:00 09:00 12:00 15:00
Ppv_tot
Battery Active Power
4 kW
3 kW
2 kW
1 kW
0 W
18:00 21:00 00:00 03:00 06:00 09:00 12:00 15:00
Pbss
State of Charge
100%
95%
90%
85%
80%
75%
70%
20:00 00:00 04:00 08:00 12:00 16:00
SOC
Battery Control Panel
BSS Control Button
Pcharge=0kW & Q=0kVar
BSS Control Button
Pcharge=1kW & Q=0kVar
BSS Control Button
Pcharge=2kW & Q=0kVar
BSS Control Button
Pcharge=3kW & Q=0kVar
BSS Control Button
Pdischarge=1kW & Q=0kVar
BSS Control Button
Pdischarge=2kW & Q=0kVar
BSS Control Button
Pdischarge=3kW & Q=0kVar
BSS Control Button
Pcharge=1kW & Q=-0.5kVar
BSS Control Button
Pcharge=2kW & Q=-1kVar
BSS Control Button
Pcharge=3kW & Q=-1.5kVar

Energy Storage Pilots’ Development

EMPOWER

EMPOWER Pilot II - Energy Storage for active distribution grids – (grid level)



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Energy Storage Pilots' Development

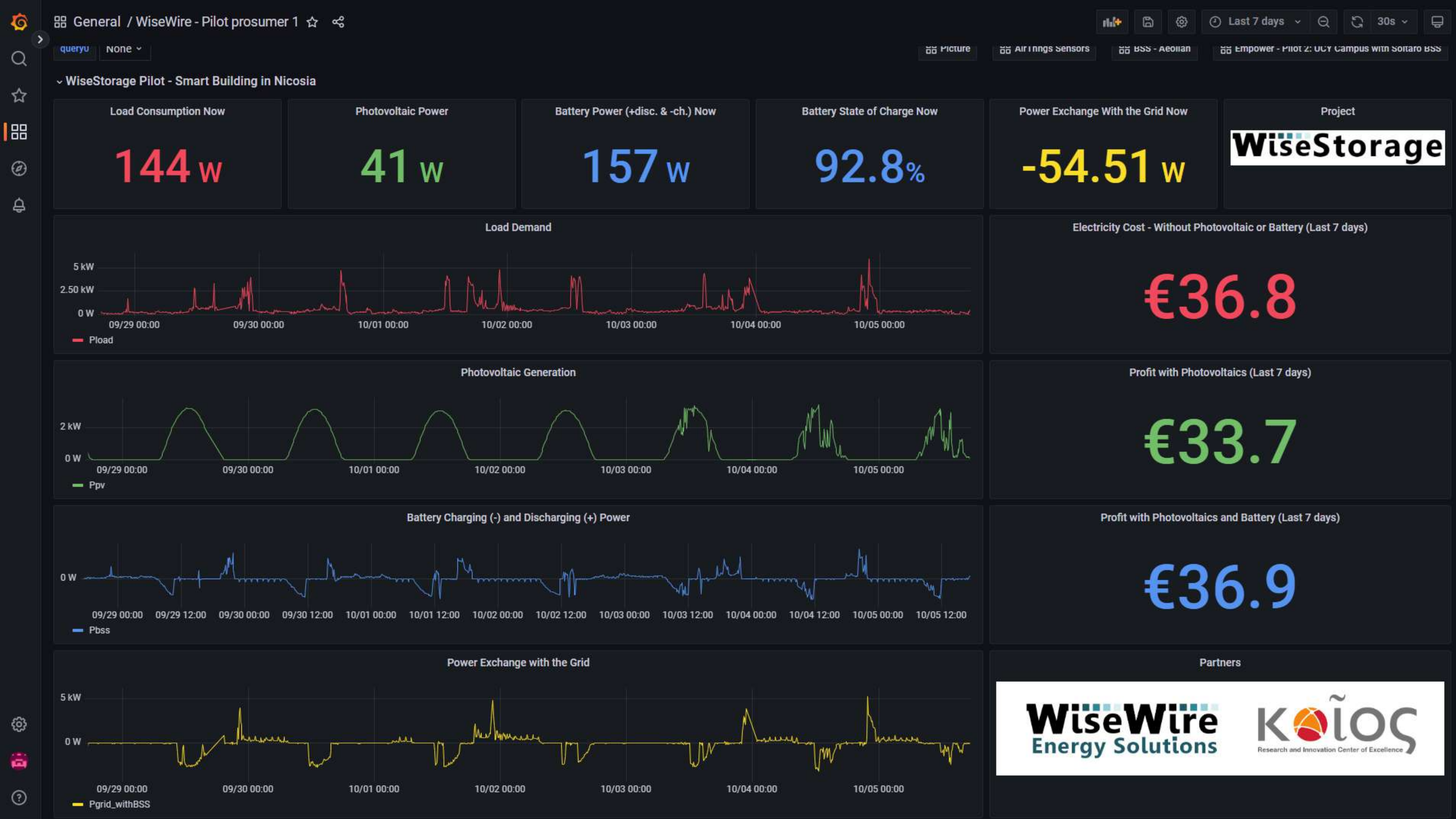
WiseStorage

WiseStorage Pilot - Energy Storage for smart buildings (building level)

WiseStorage »

WiseWire Energy Solutions

Kõios Research and Innovation Center of Excellence


General / WiseWire - Pilot prosumer 1
Last 7 days
30s
query0
None
Picture
AirThings Sensors
BSS - Aeolian
Empower - Pilot 2: UCY Campus with Sofraro BSS
WiseStorage Pilot - Smart Building in Nicosia
Load Consumption Now
144 W
Photovoltaic Power
41 W
Battery Power (+disc. & -ch.) Now
157 W
Battery State of Charge Now
92.8%
Power Exchange With the Grid Now
-54.51 W
Project
WiseStorage
Load Demand
5 kW
2.50 kW
0 W
09/29 00:00
09/30 00:00
10/01 00:00
10/02 00:00
10/03 00:00
10/04 00:00
10/05 00:00
Pload
Electricity Cost - Without Photovoltaic or Battery (Last 7 days)
€36.8
Photovoltaic Generation
2 kW
0 W
09/29 00:00
09/30 00:00
10/01 00:00
10/02 00:00
10/03 00:00
10/04 00:00
10/05 00:00
Ppv
Profit with Photovoltaics (Last 7 days)
€33.7
Battery Charging (-) and Discharging (+) Power
0 W
09/29 00:00
09/29 12:00
09/30 00:00
09/30 12:00
10/01 00:00
10/01 12:00
10/02 00:00
10/02 12:00
10/03 00:00
10/03 12:00
10/04 00:00
10/04 12:00
10/05 00:00
10/05 12:00
Pbss
Profit with Photovoltaics and Battery (Last 7 days)
€36.9
Power Exchange with the Grid
5 kW
0 W
09/29 00:00
09/30 00:00
10/01 00:00
10/02 00:00
10/03 00:00
10/04 00:00
10/05 00:00
Pgrid_withBSS
Partners
WiseWire
Energy Solutions
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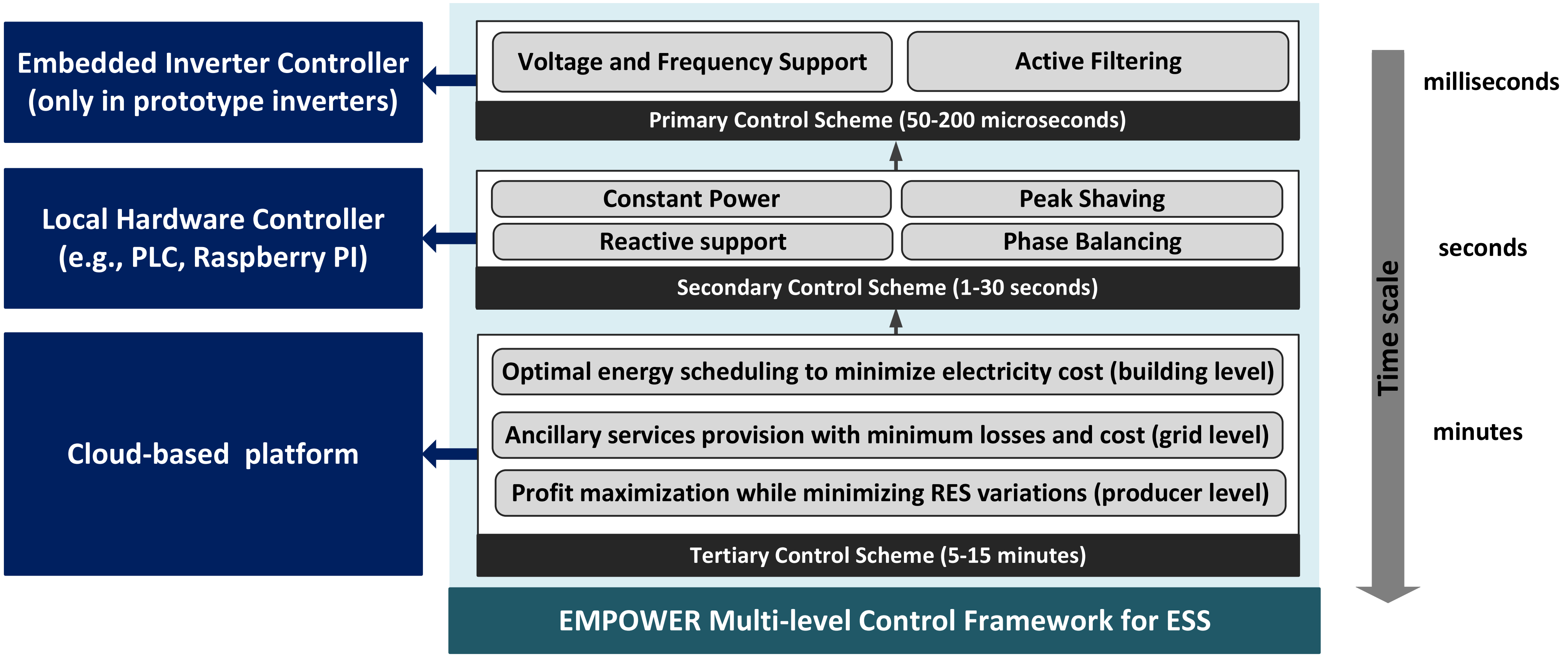
Intelligent Control and Management Solutions

Intelligent Control and Management

- **Each ESS pilot may have common or different objectives**
- **Each control scheme (primary/secondary/tertiary) should be integrated at a different level (e.g., inverter controller, local controller, cloud platform)**



Intelligent Control and Management

Primary Control Schemes

- **<u>Voltage and Frequency Support</u> to enhance system stability**
  - **An advanced control scheme is developed for the ESS inverter [1] to:**
    - **Coordinate between voltage and frequency support according to fault characteristics**
    - **Enhance frequency support** by providing <u>droop control</u> and <u>virtual inertia</u> to mimic the response of conventional generators → $\Delta P = k_f|\Delta f| + \frac{2H_{vi}S_n}{Vf_n} \cdot \frac{df}{dt}$
    - **Provide optimal voltage support** for ESS connected to the distribution grids by controlling both active and reactive power
  - **Integration of the primary controller to the prototype inverter**

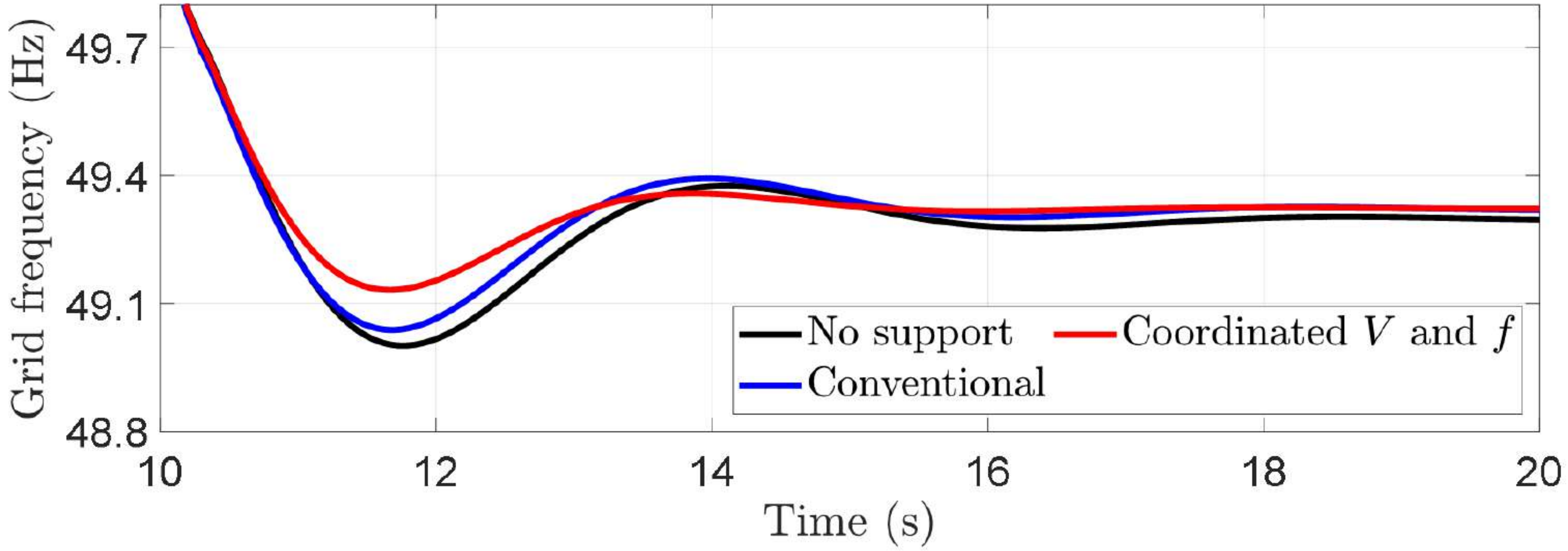
Prototype Storage Inverter

[1] A. Charalambous, L. Hadjidemetriou, E. Kyriakides, M. Polycarpou, "A coordinated voltage-frequency support scheme for storage systems connected to distribution grids," *IEEE Trans. Power Electronics*, vol. 36, no. 7, pp. 8464-8475, July. 2021

Intelligent Control and Management

Primary Control Schemes

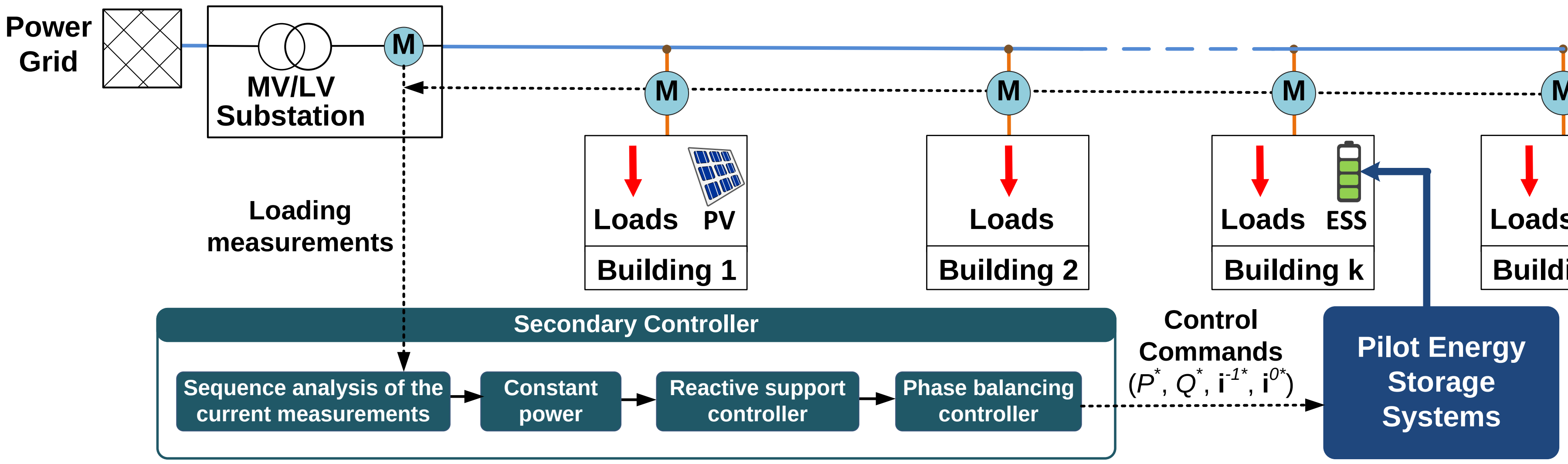
- **<u>Voltage and Frequency Support</u> to enhance system stability**
  - **Impact of the proposed control method on power system stability:**
    - **Voltage stability →** 8-10% average improvement
    - **Frequency stability →** 20% improvement on frequency nadir and RoCoF



Intelligent Control and Management

Secondary Control Schemes

- **Constant power, reactive support and phase balancing scheme**
  - **Constant power** → regulate the active power exchange with the grid
  - **Reactive support** → to achieve a unity power factor (reactive power equals to zero)
  - **Phase balancing** → to symmetrize the loading conditions among the three phases (either by using advanced controller for 3-phase inverter [2] or by using three individual 1-phase inverters)



Soltaro Battery Storage

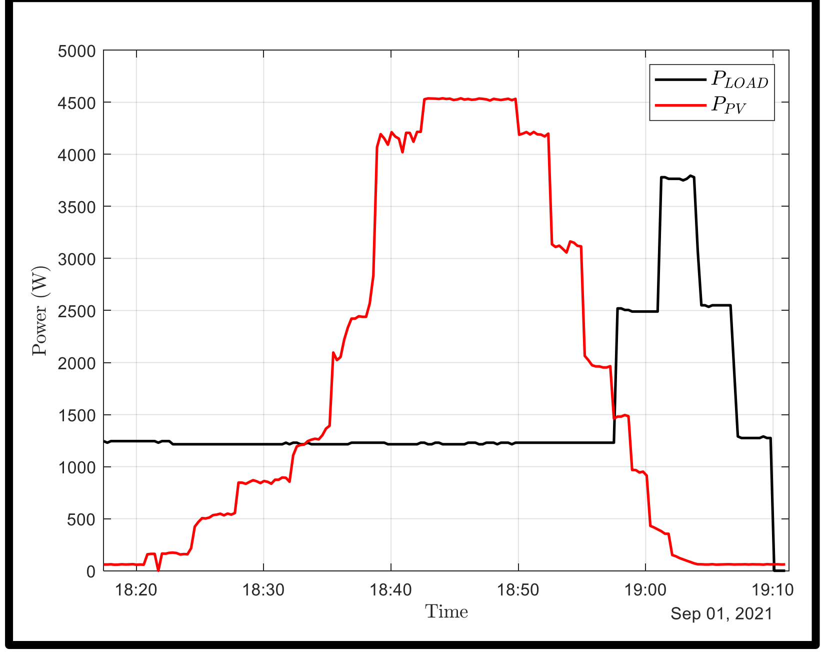
[2] Z. Ali, N. Christofides, L. Hadjidemetriou, E. Kyriakides, "Diversifying the role of distributed generation grid side converters for improving the power quality of distribution networks using advanced control techniques", *IEEE Trans. Industry Appl.* vol. 55, no. 4, pp. 4110-4123, Aug. 2019.

Intelligent Control and Management

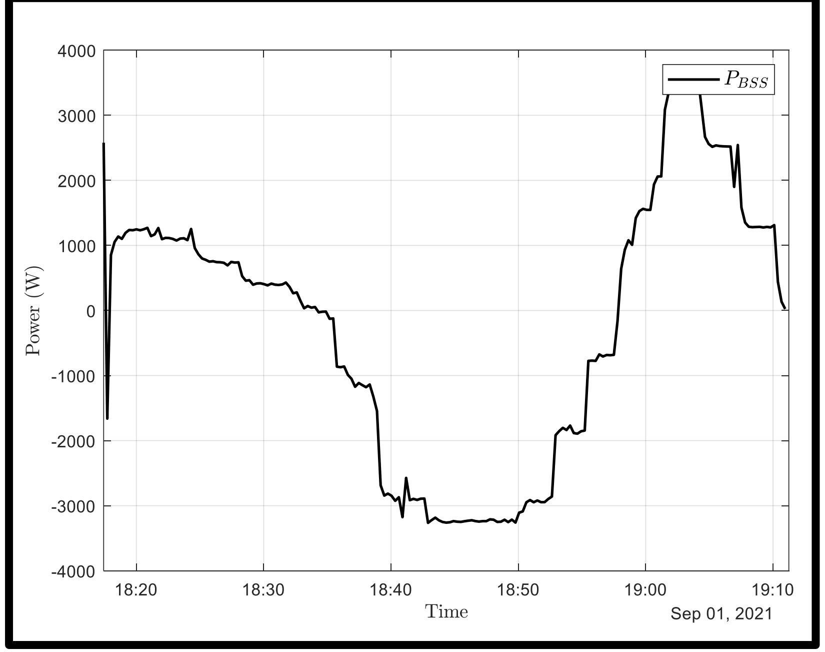
Secondary Control Schemes

- **Constant power, Reactive support and Phase balancing scheme**
  - **Pilot results for constant power mode**

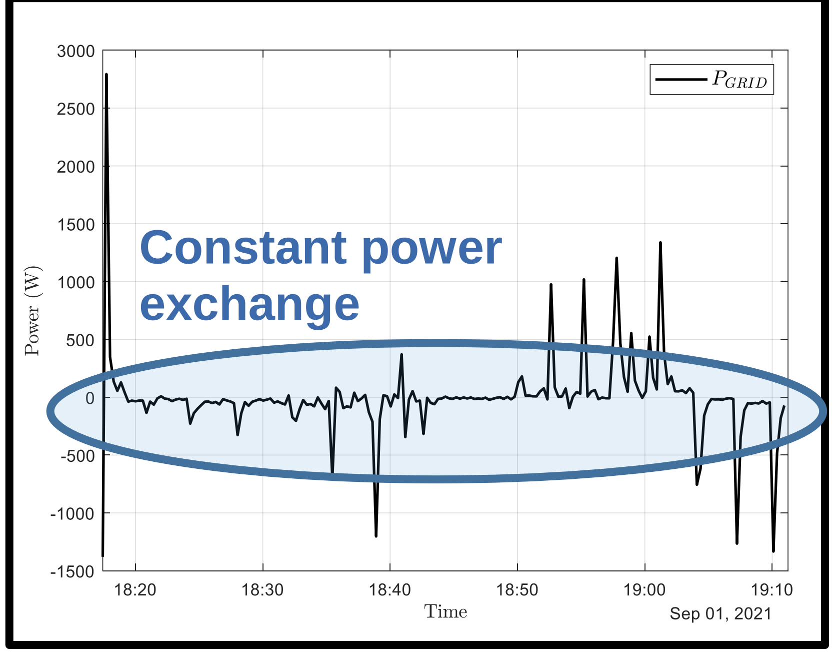
PV generation – Load consumption



ESS operation



Exchange power with the grid

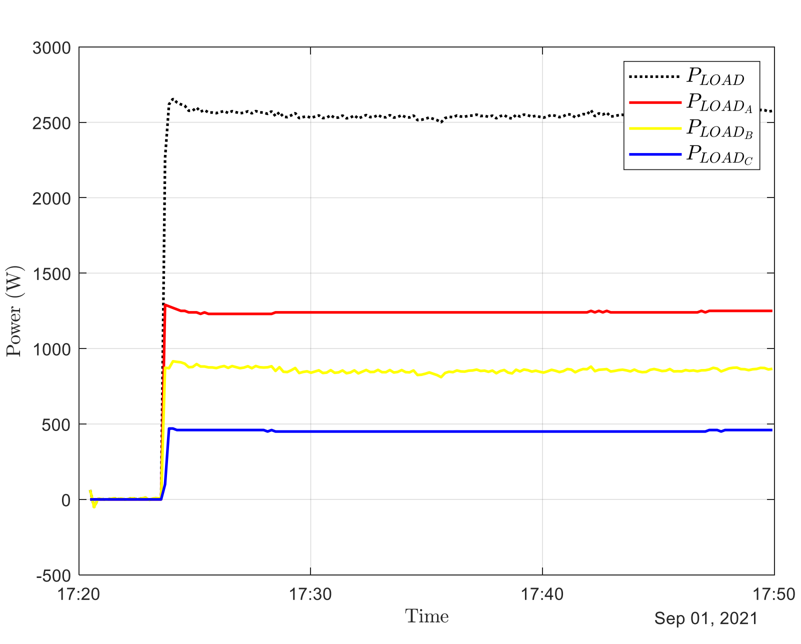


Intelligent Control and Management

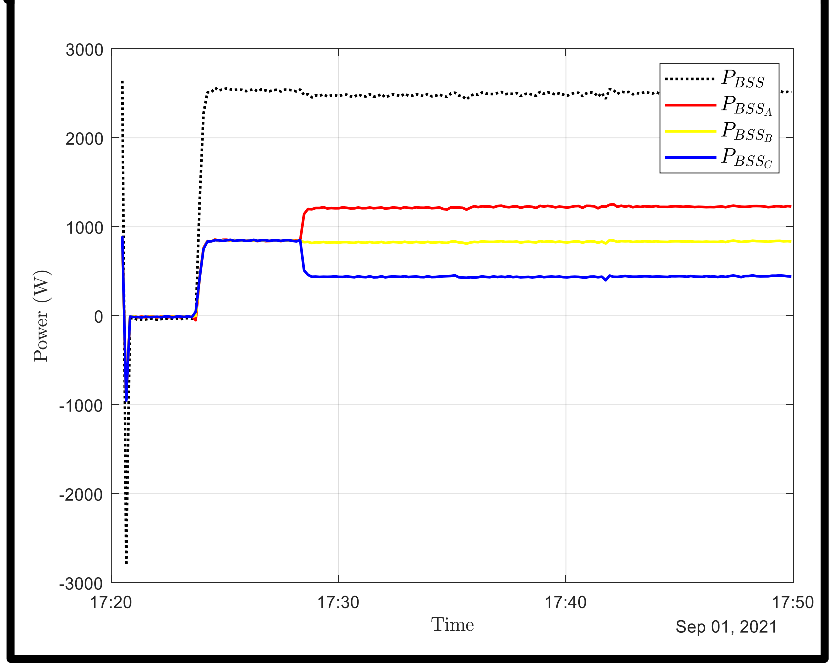
Secondary Control Schemes

- **<u>Constant power, Reactive support and Phase balancing scheme</u>**
  - **Pilot results for phase balancing mode**

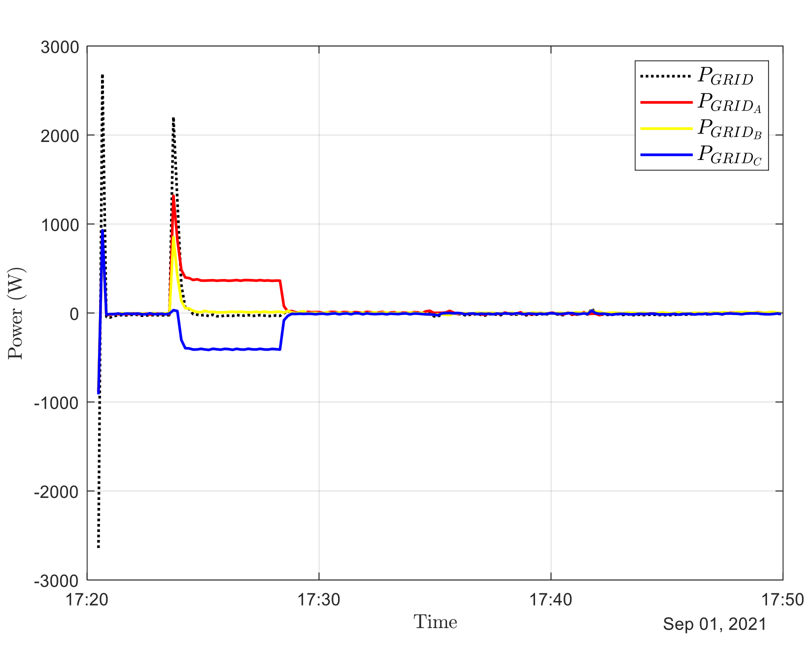
Load consumption



ESS operation



Exchange power with the grid



Intelligent Control and Management

Secondary Control Schemes

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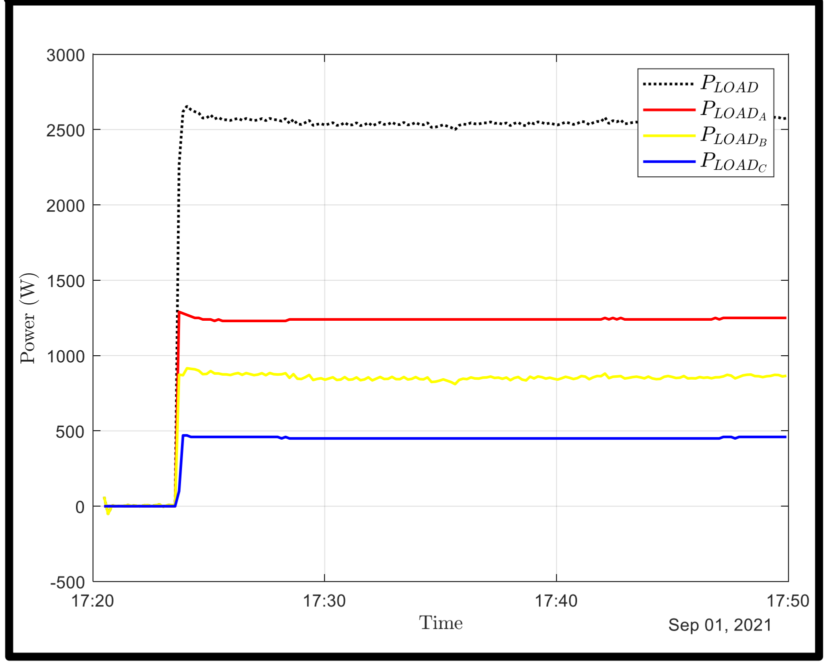
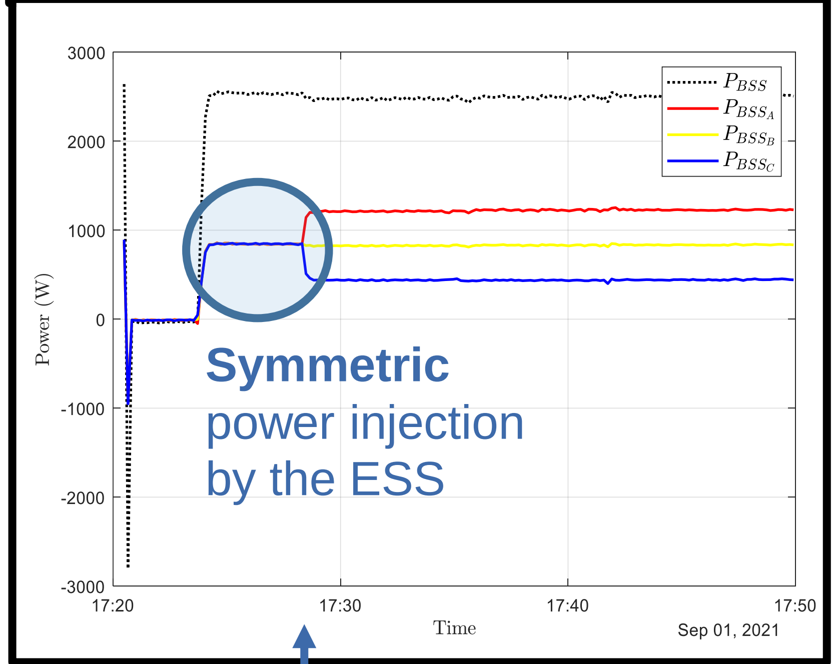
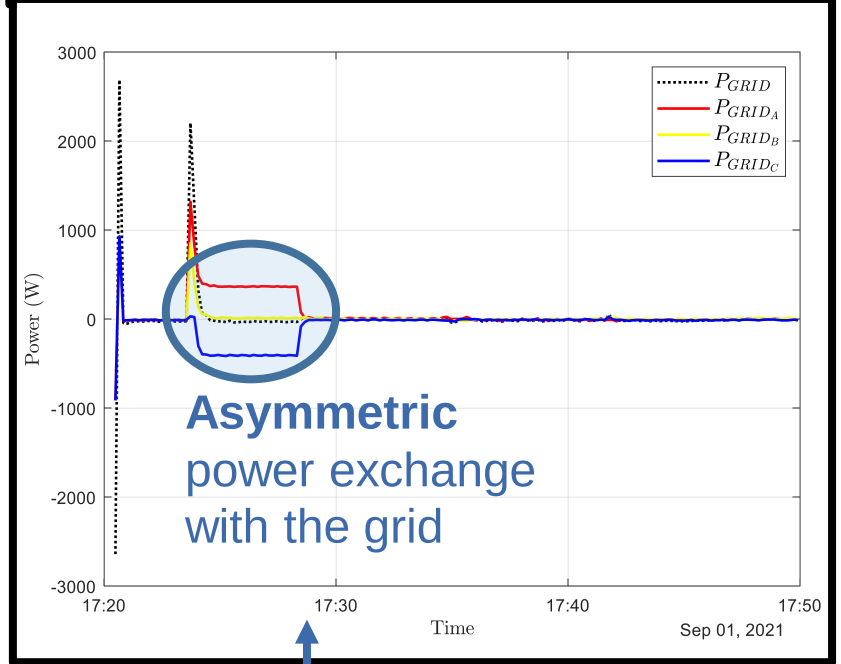
Load consumption



ESS operation



Exchange power with the grid



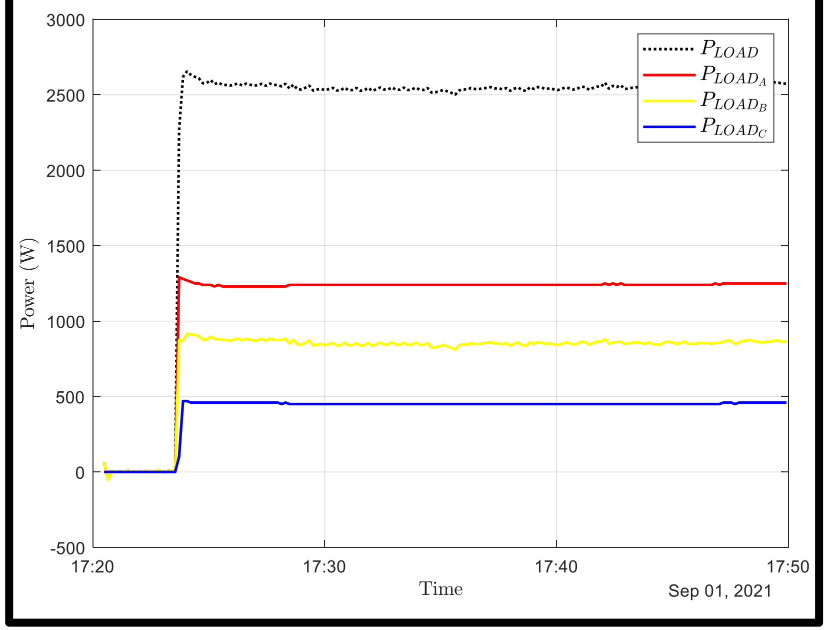
Activation of phase balancing mode

Intelligent Control and Management

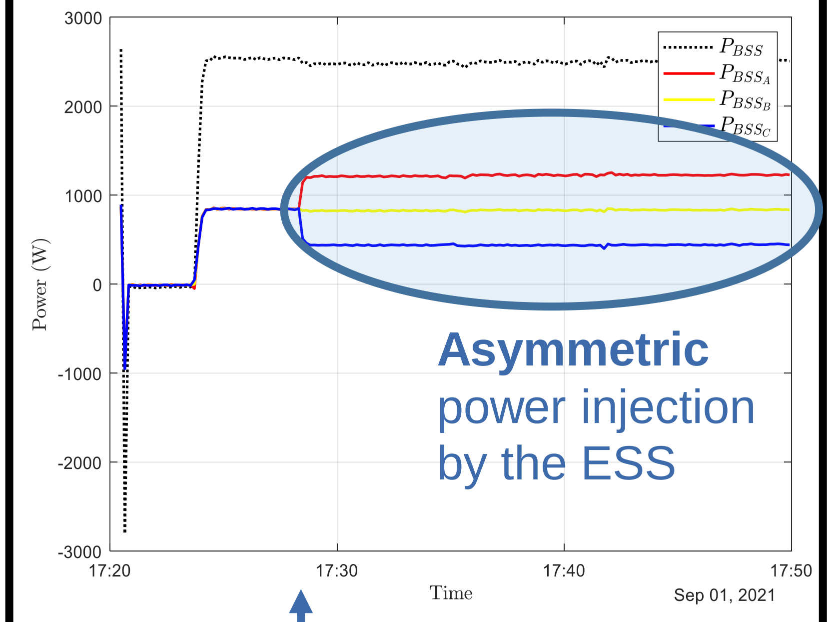
Secondary Control Schemes

- **<u>Constant power, Reactive support and Phase balancing scheme</u>**
  - **Pilot results for phase balancing mode**

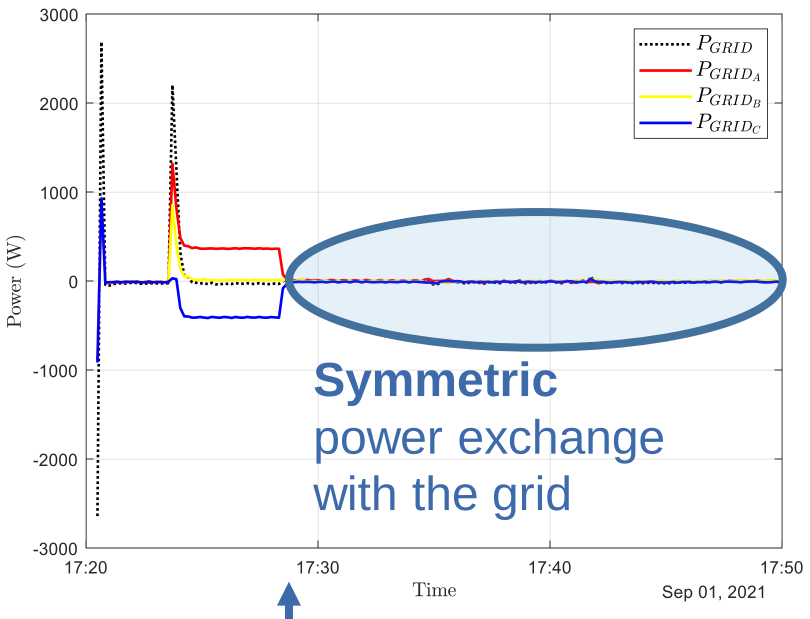
Load consumption



ESS operation



Exchange power with the grid



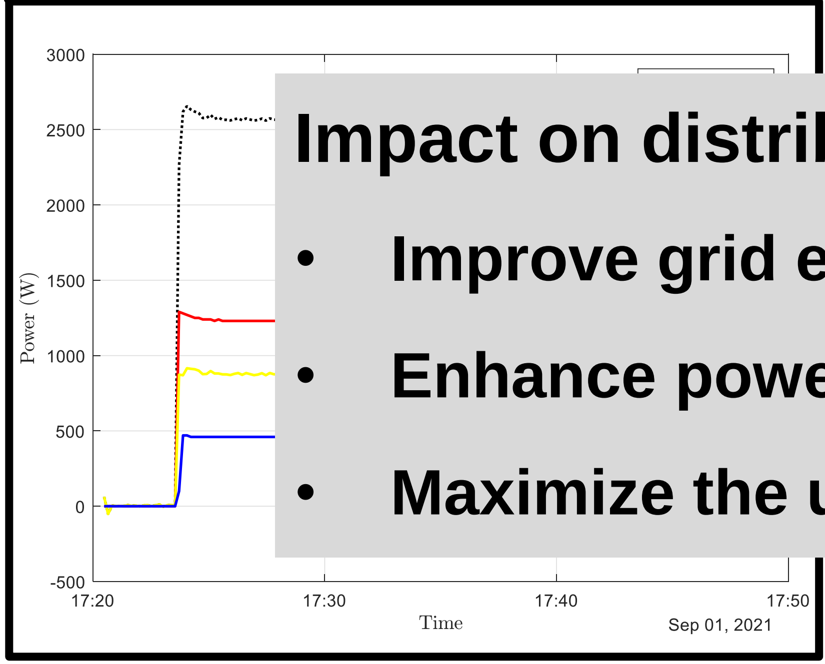
Activation of phase balancing mode

Intelligent Control and Management

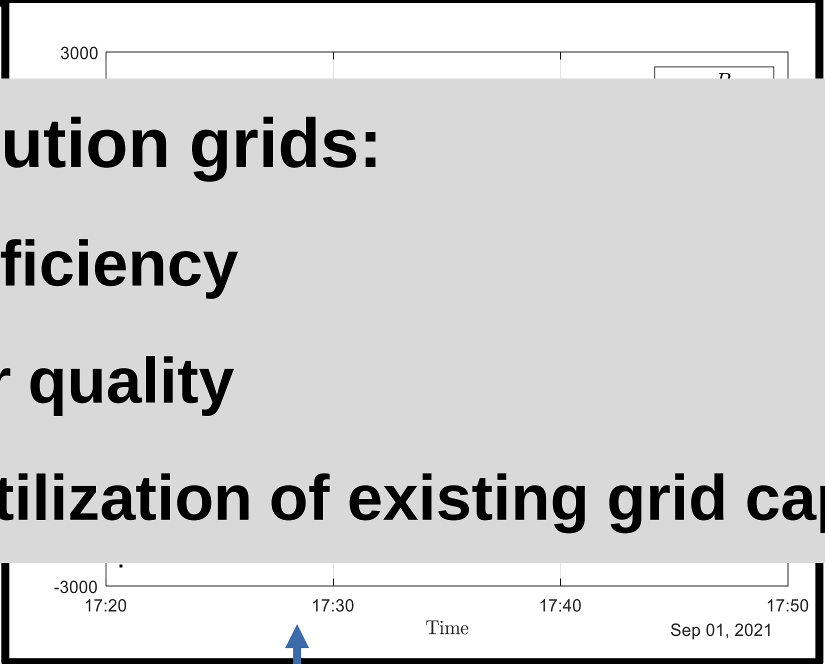
Secondary Control Schemes

- **Constant power, Reactive support and Phase balancing scheme**
  - **Pilot results for phase balancing mode**

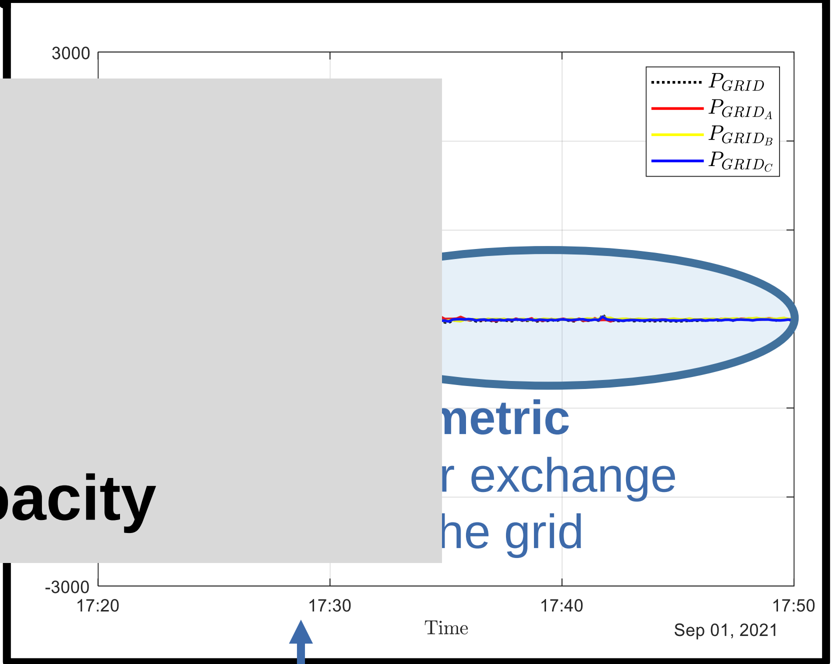
Load consumption



ESS operation



Exchange power with the grid



Impact on distribution grids:

- **Improve grid efficiency**
- **Enhance power quality**
- **Maximize the utilization of existing grid capacity**

Activation of phase balancing mode

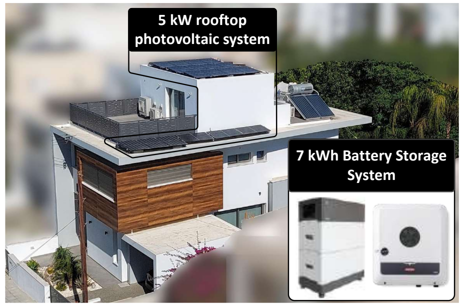
Intelligent Control and Management

A different Tertiary Control Scheme for each pilot

- **EMPOWER Pilot I - Energy Storage and RES – (producer level)**
  - **Maximize profit and controllability**

- **EMPOWER Pilot II - Energy Storage for active distribution grids – (grid level)**
  - **Optimal peak-shaving services**

- **WiseStorage Pilot - Energy Storage for smart buildings (building level)**
  - **Electricity cost minimization**



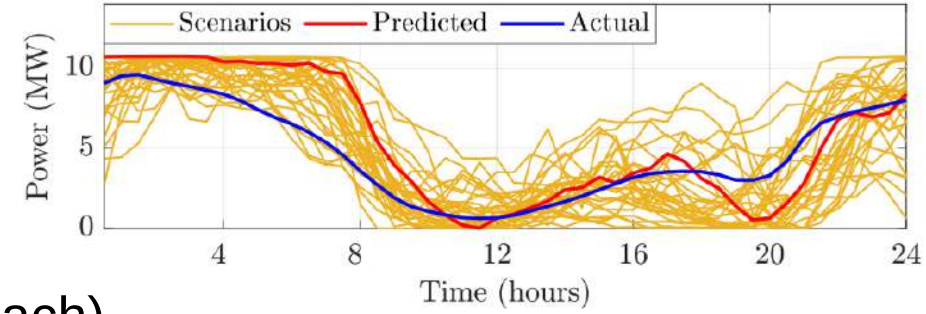
Intelligent Control and Management

A different Tertiary Control Scheme for each pilot

- **EMPOWER Pilot I - Energy Storage and RES – (producer level)**

Maximize profit and controllability [3]

- Intelligent robust/stochastic optimization to maximize profit and minimize power violations (due to forecasting uncertainties)
- Consider multiple historical forecasting-generation scenarios
- Real-time control of storage operation in the pilot site



Results

- **Stochastic optimization** (compared to deterministic approach)
  - **Profit:** 7.5% increase - **Power violations:** 31% decrease
- **Robust optimization** (compared to deterministic)
  - **Profit:** 6.5% increase - **Power violation:** 59% decrease

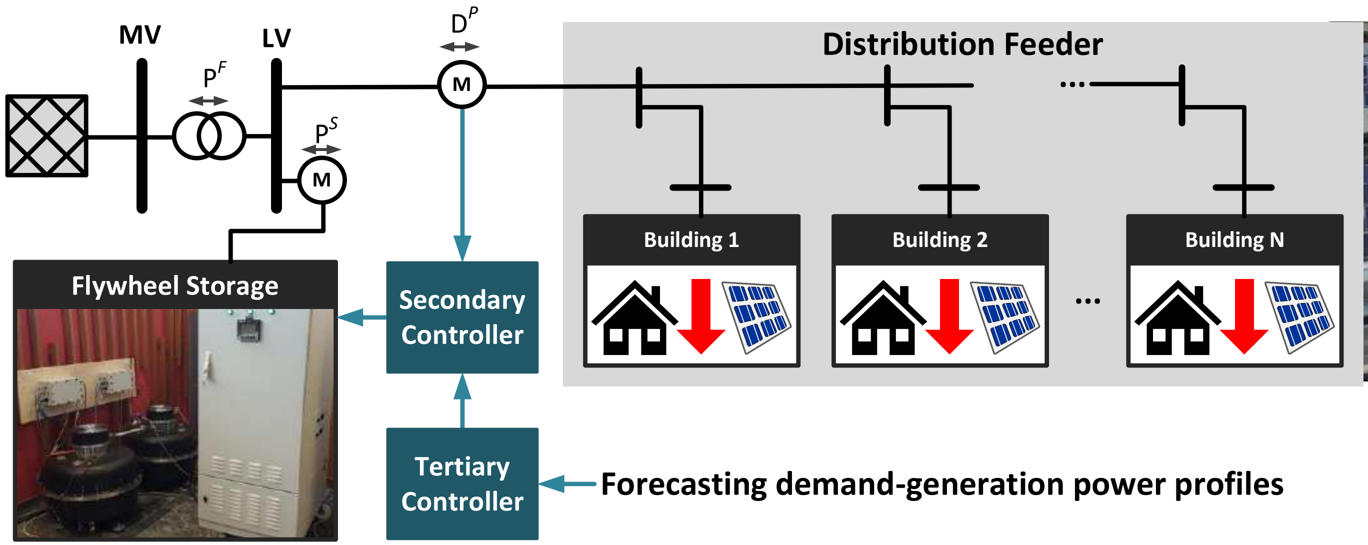
[3] L. Tziovani, L. Hadjidemetriou, S. Timotheou, "Energy scheduling of wind-storage systems using stochastic and robust optimization," in Proc. IEEE PES General Meeting, Denver, USA, 2022, pp. 1-5.

Intelligent Control and Management

A different Tertiary Control Scheme for each pilot

- **EMPOWER Pilot II - Energy Storage for active distribution grids – (grid level)**

  Optimal peak-shaving services [4]
  - **Modeling:** Flywheel storage modeling using standard-form convex expressions
  - **Secondary controller:** to provide peak-shaving services under uncertainties
  - **Tertiary controller:** A novel lexicographic optimization to prioritize different objectives (first to minimize power-energy transformer violations and then to minimize energy losses)



[4] L. Tziovani, L. Hadjidemetriou, C. Charalampous, M. Tziakouri, S. Timotheou, E. Kyriakides, “Energy management and control of a flywheel storage system for peak shaving applications,” *IEEE Tran. Smart Grid*, vol. 12, no. 5, pp. 4195-4207, Sep. 2021.

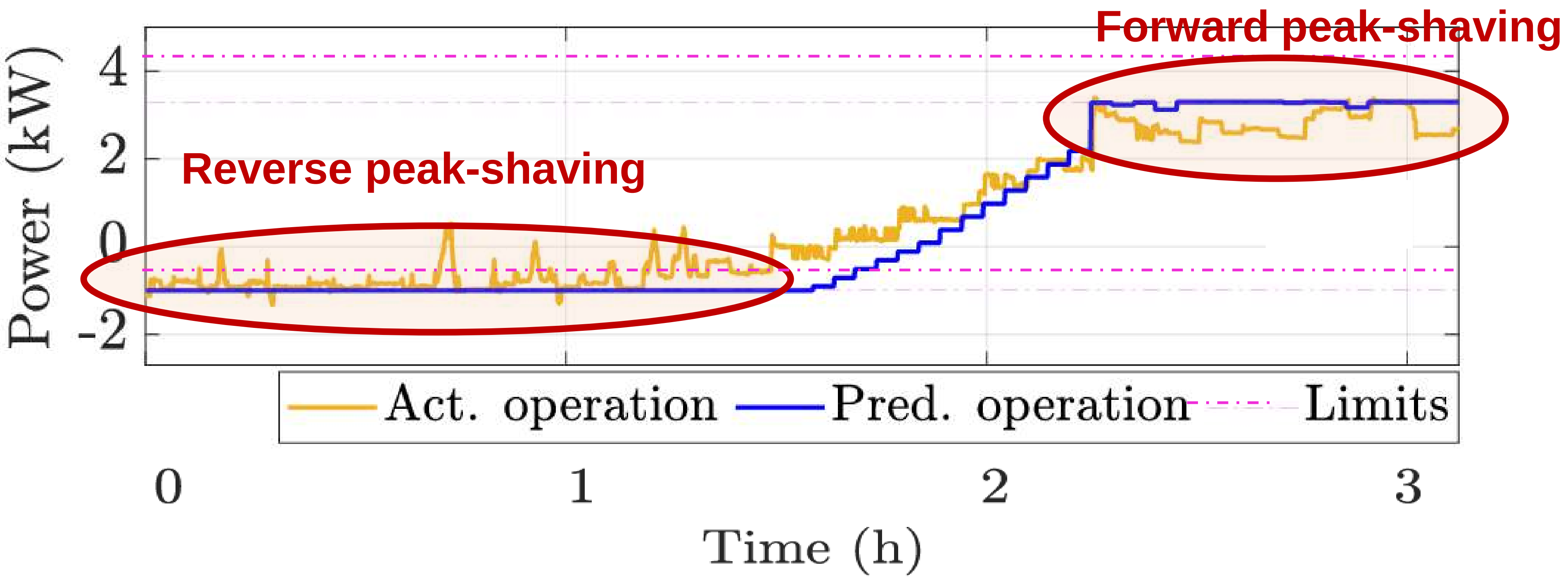
Intelligent Control and Management

A different Tertiary Control Scheme for each pilot

- **EMPOWER Pilot II - Energy Storage for active distribution grids – (grid level)**

  Optimal peak-shaving services [4]

  - **Results:** Effective peak shaving with minimum losses

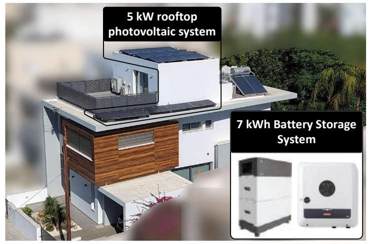


[4] L. Tziovani, L. Hadjidemetriou, C. Charalampous, M. Tziakouri, S. Timotheou, E. Kyriakides, "Energy management and control of a flywheel storage system for peak shaving applications," *IEEE Tran. Smart Grid*, vol. 12, no. 5, pp. 4195-4207, Sep. 2021.

Intelligent Control and Management

WiseStorage

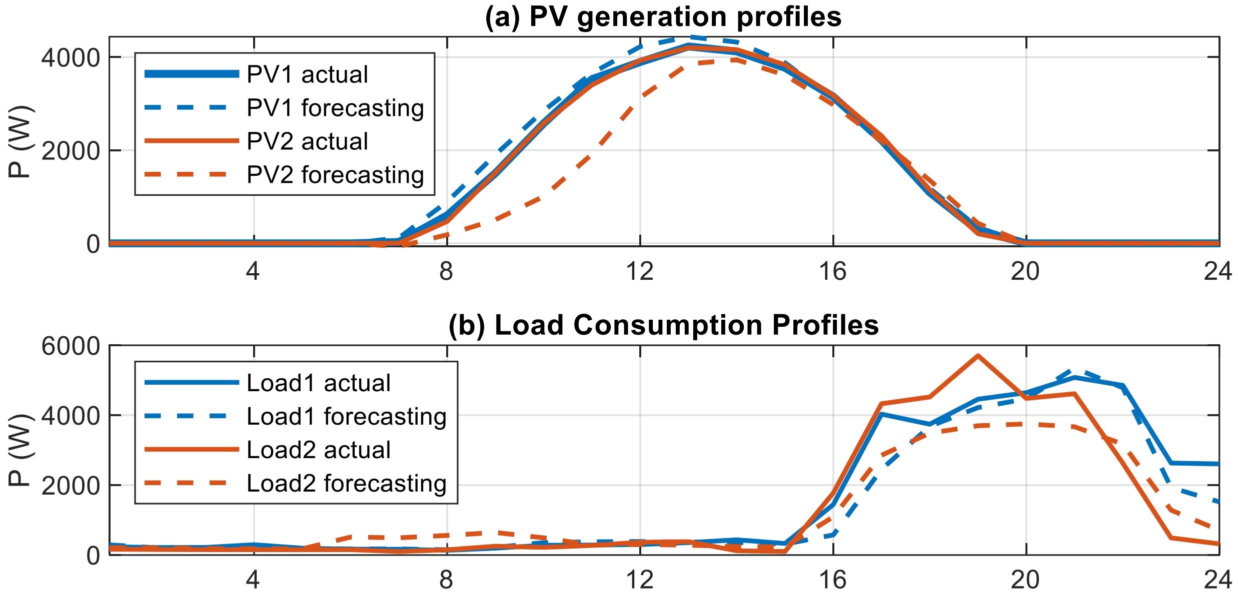
A different Tertiary Control Scheme for each pilot



- **WiseStorage Pilot - Energy Storage for smart buildings**

Electricity cost minimization [5]

- Intelligent forecasting of demand-generation
- Energy management optimization under:
  - Net-billing framework
  - Variable pricing scheme (Spain)
  - Low (PV1/Load1) or high (PV2/Load2) forecasting uncertainties



Results (compared to self-consumption mode)

- **Self-consumption mode:** 6-25% electricity cost reduction (compared to no battery scenario)
- **Proposed intelligent mode:** 20-40% electricity cost reduction (compared to no battery scenario)

[5] L. Tziovani, P. Kolios, L. Hadjidemetriou, E. Kyriakides, "Grid friendly operation with profit and reliability maximization of a hybrid photovoltaic-storage system," in Proc. IEEE SEST, Porto, Portugal, 2019, pp. 1-6.

Conclusion

- **Though the EMPOWER project an intelligent three-level control framework has been developed for energy storage systems to:**
  - Advance the grid integration of renewable energy
  - Enhance power system stability
  - Improve efficiency, power quality and grid utilization
  - Reduce electricity cost and maximize profit
- **The intelligent control and management solutions have been validated and demonstrated in three operational pilots considering**
  - Energy storage at the renewable energy producer level
  - Community storage for grid level applications
  - Energy storage for smart building or prosumers
- **Intelligent energy storage systems can increase the competitiveness of green technologies and can maximize the renewable energy penetration level**

Thank you for your attention

EMPOWER

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WiseStorage

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European Union

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