New technologies and new prospects for the integration of renewable energy in the power system grid

Elias Kyriakides

Associate Director, KIOS Research Center

Associate Professor, Department of Electrical and Computer Engineering

University of Cyprus

elias@ucy.ac.cy

Presentation Outline

- University of Cyprus – KIOS Research Center
- The PV2Grid project
- Low voltage grid monitoring and control
- The ENHANCE project
- Other activities

KIOS Research Center - Background

- **KIOS Research and Innovation Center of Excellence**
- **Founded in 2008**
- **The KIOS Research Center is part of the University of Cyprus**
- **Housed (mainly) at the KIOS Center Building (600 m^2)**
- **Web site: www.kios.ucy.ac.cy**
- **TEAMING/H2020 (KIOS/Imperial – funding of ~40 m€)**
- **About 90 researchers (goal to reach 200 by 2020)**
  - ***8 faculty members***
  - ***~30 post-doctoral fellows***
  - ***~50 Ph.D. students***
  - ***Several M.Sc. students and non-degree researchers***

KIOS
Research and Innovation Centre of Excellence

Technical Focus of the KIOS CoE

- **Intelligent monitoring, management and security of complex, large-scale dynamical systems**
- **Application domain: *Critical Infrastructure Systems***

Power Systems

- Increase stability, fault tolerance
- Reduce emissions, energy consumption, generation costs
- Integrate renewable energy sources

Water Networks

- Increase security, water quality, resilience
- Reduce water losses, energy usage, non-revenue water

Telecommunications

- Improve network coverage and mobility, reliability, secrecy, data-rates
- Reduce energy consumption

Transportation Networks

- Increase mobility and productivity
- Reduce accidents, fuel consumption, emissions, congestion cost

Emergency Response

- Reduce damage of ecosystem, damage to property and destruction of critical infrastructures

KIOS Research and Innovation Centre of Excellence

Research Areas of Power Systems Group

- Operation and control of the power system
- Wide area monitoring and control
- Grid integration of renewables
- Control of power electronic converters
- Economic dispatch
- Micro-grids and Smart-grids
- Load shedding
- Load modelling
- Storage

KOIOS
Research and Innovation Centre of Excellence

The PV2Grid Project

A next generation grid side converter with advanced control and power quality capabilities

- **KIOS Research Center – University of Cyprus (Coordinator)**
- **Department of Energy Technology - Aalborg University**
- **Quantum Energy Corporation Ltd**

- ✓ **This project aims to advance the technology related to the seamless grid integration of photovoltaic (PV) systems.**
- ✓ **Development of next generation power electronic Grid Side Converters (GSC) with advanced capabilities and innovative operational management approaches.**

SOLAR-ERA.NET

Research Promotion Foundation

ENERGINET.DK

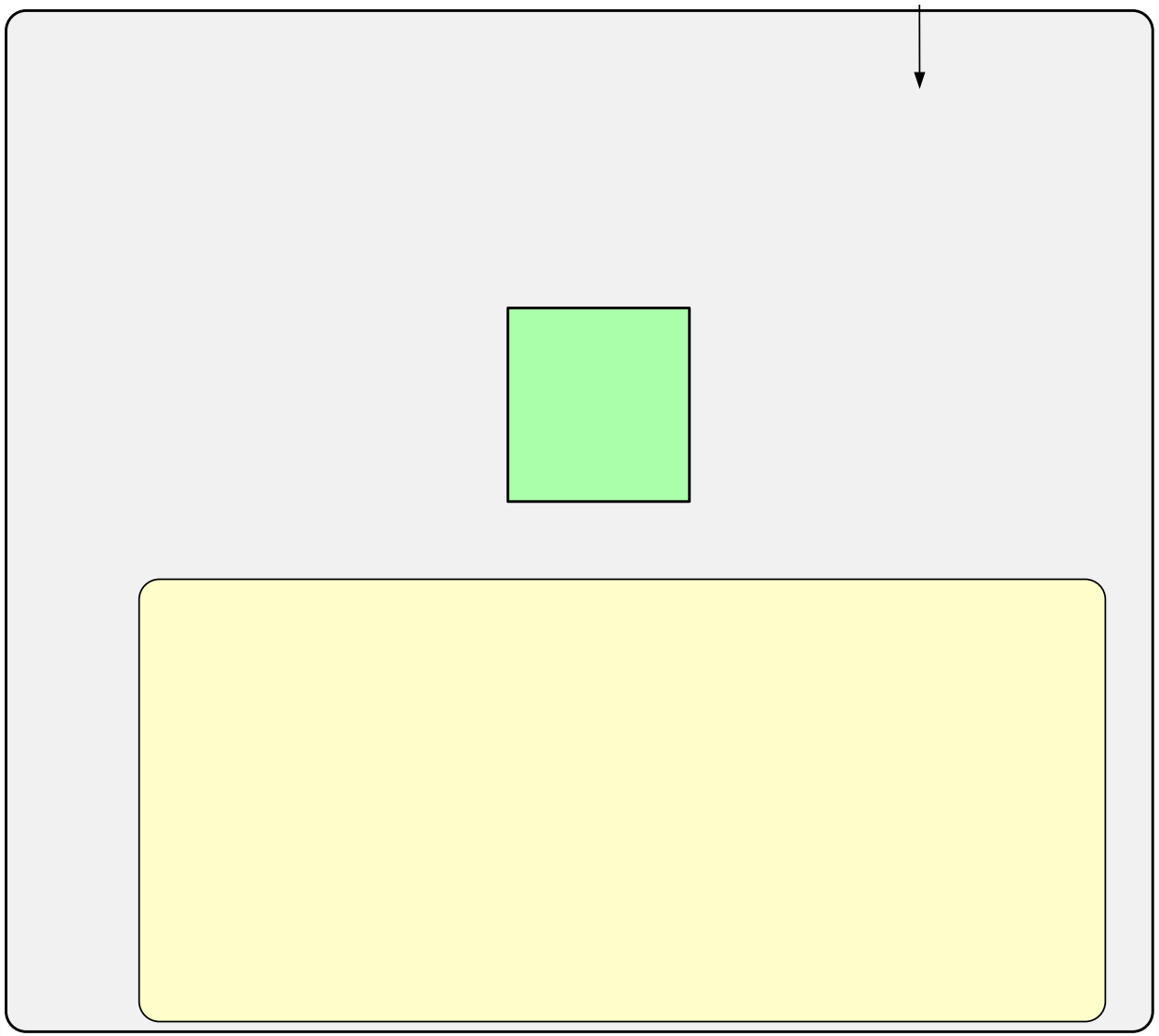
KIOS Research and Innovation Centre of Excellence

The PV2Grid Project – Objectives

- **Design and develop new generation Grid Side Converters (GSCs) equipped with advanced control capabilities and novel operational mode approaches:**
  - ✓ **providing support to the grid when needed**
  - ✓ **enhancing the power system stability**
  - ✓ **improving the power quality of the grid**
  - ✓ **reducing the network losses**
- **Design new current controllers: inject positive, negative (in case of three-phase GSCs) and harmonic-free currents under normal or abnormal voltage conditions.**
- **Develop experimental prototypes of GSCs including the current control techniques and the PQ controllers.**

KOIOS
Research and Innovation Centre of Excellence

Architecture of the Proposed GSC



Development of advanced PQ controllers

Goal: Enable new flexible operation modes for PV inverters

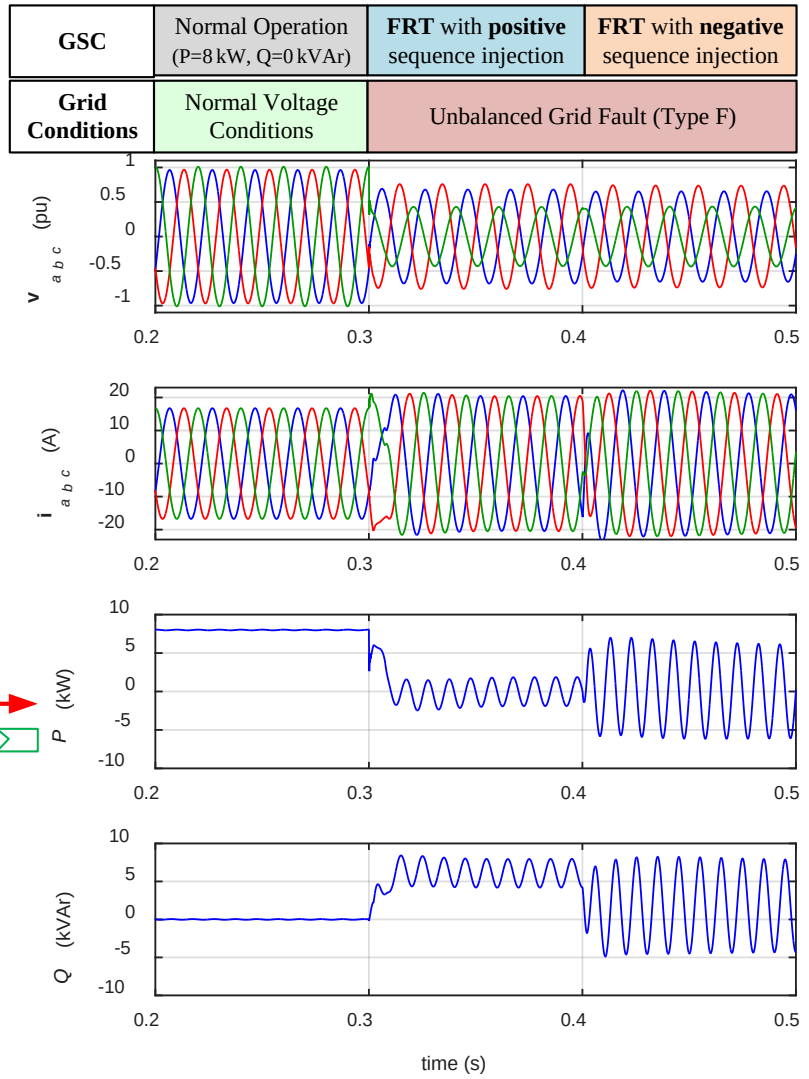
a. Fault Ride Through (FRT) operation of residential PVs under grid faults

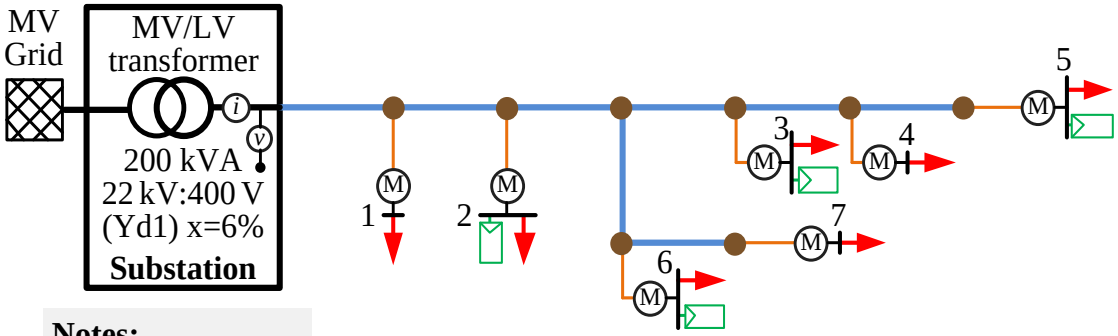
b. Operating mode for the PV inverters to symmetrize the prosumer's load unbalances for benefiting the distribution grid operation

KOIOS
Research and Innovation Centre of Excellence

FRT operation of residential PVs

- Provide positive sequence FRT support
- Provide both positive and negative sequence FRT support
- Investigate effect on a realistic LV distribution grid





Notes:

- 4x100 mm^2 OH Aluminum line (Wasp)
- (2 or 4)x22 mm^2 OH Aluminum line (Midge)
- 10 m wooden poles
- Consumer's Meter
- Consumer's Load
- Consumer's PV

FRT operation of residential PVs

Effect on a realistic LV distribution grid

- **Positive sequence FRT support → voltage rise by 2-3%**
- **Positive and negative sequence FRT support → voltage rise by 1-2% and asymmetries reduction by 1-2%**

Operation of RESs during a grid fault	Voltage at selected busses of the DN					
	MV/LV transformer	*Prosumer 2*	*Prosumer 3*	*Prosumer 5*	*Prosumer 6*	*Consumer 7*
(a) RES disconnected	$\|\mathbf{v}^+\|$=0.599 $\|\mathbf{v}^-\|$=0.198	$\|\mathbf{v}^+\|$=0.589 $\|\mathbf{v}^-\|$=0.192	$\|\mathbf{v}^+\|$=0.584 $\|\mathbf{v}^-\|$=0.190	$\|\mathbf{v}^+\|$=0.583 $\|\mathbf{v}^-\|$=0.189	$\|\mathbf{v}^+\|$=0.585 $\|\mathbf{v}^-\|$=0.190	$\|\mathbf{v}^+\|$=0.585 $\|\mathbf{v}^-\|$=0.190
(b) RES without FRT support	$\|\mathbf{v}^+\|$=0.601 $\|\mathbf{v}^-\|$=0.199	$\|\mathbf{v}^+\|$=0.593 $\|\mathbf{v}^-\|$=0.200	$\|\mathbf{v}^+\|$=0.593 $\|\mathbf{v}^-\|$=0.198	$\|\mathbf{v}^+\|$=0.589 $\|\mathbf{v}^-\|$=0.201	$\|\mathbf{v}^+\|$=0.594 $\|\mathbf{v}^-\|$=0.197	$\|\mathbf{v}^+\|$=0.593 $\|\mathbf{v}^-\|$=0.197
(c)RES with positive sequence FRT	$\|\mathbf{v}^+\|$=**0.611** $\|\mathbf{v}^-\|$=0.198	$\|\mathbf{v}^+\|$=**0.608** $\|\mathbf{v}^-\|$=0.192	$\|\mathbf{v}^+\|$=**0.608** $\|\mathbf{v}^-\|$=0.189	$\|\mathbf{v}^+\|$=**0.608** $\|\mathbf{v}^-\|$=0.188	$\|\mathbf{v}^+\|$=**0.608** $\|\mathbf{v}^-\|$=0.189	$\|\mathbf{v}^+\|$=**0.608** $\|\mathbf{v}^-\|$=0.190
(d)RES with positive and negative sequence FRT	$\|\mathbf{v}^+\|$=0.605 $\|\mathbf{v}^-\|$=**0.192**	$\|\mathbf{v}^+\|$=0.598 $\|\mathbf{v}^-\|$=**0.182**	$\|\mathbf{v}^+\|$=0.596 $\|\mathbf{v}^-\|$=**0.176**	$\|\mathbf{v}^+\|$=0.595 $\|\mathbf{v}^-\|$=**0.174**	$\|\mathbf{v}^+\|$=0.598 $\|\mathbf{v}^-\|$=**0.178**	$\|\mathbf{v}^+\|$=0.598 $\|\mathbf{v}^-\|$=**0.179**

KIOC
Research and Innovation Centre of Excellence

Industrial project: Monitoring of the LV grid

- **There is an urgent need to monitor LV networks. The Electricity Authority of Cyprus has contracted us to develop a monitoring technique for its LV grid.**
- **System measurements will consist of:**
  - **Measurements from the MV/LV transformer**
  - **Smart meters and AMI**
  - **PV and storage inverters**
- **Different observability levels will be considered, depending on the smart meters penetration level.**
- **Selected representative low voltage feeders will be studied under various scenarios of:**
  - **PV penetration level**
  - **Seasonal Loading profiles**
  - **Level of EVs and storage devices**
- **System modeling:**
  - **EMT and/or phasor simulations in Matlab-Simulink**
  - **RTDS KIOS Testbed**

KIOS
Research and Innovation Centre of Excellence

Industrial project: Development of control techniques

- **The developed control techniques will use all available actuators:**
  - Online tap changing transformers
  - Grid tied inverters
  - Storage and EVs
  - Flexible loads
- **Different control schemes will be investigated:**
  - Reactive power compensation
  - Load shedding or load shifting
  - Storage scheduling
  - Incentive policies for the PVs
- **The developed control techniques will generate the set points of the flexible actuators**

KOIOS
Research and Innovation Centre of Excellence

The ENHANCE project

Enhanced rooftop PV integration through kinetic storage and wide area monitoring

Project Partners:

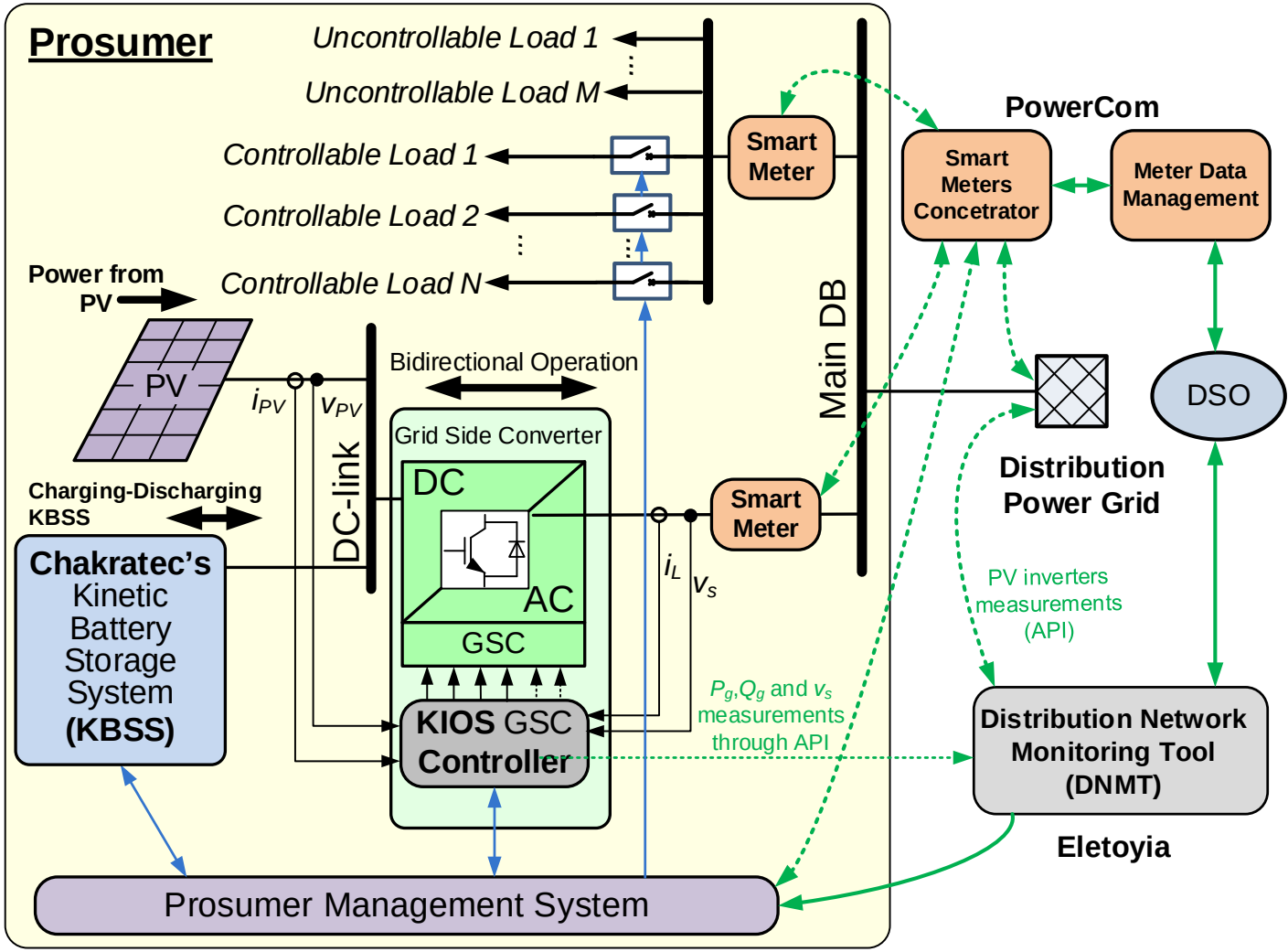
- **KIOS Research Center, University of Cyprus**
- **Eletoyia**
- **Chakratec Ltd**
- **PowerCom Ltd**

Funded by:

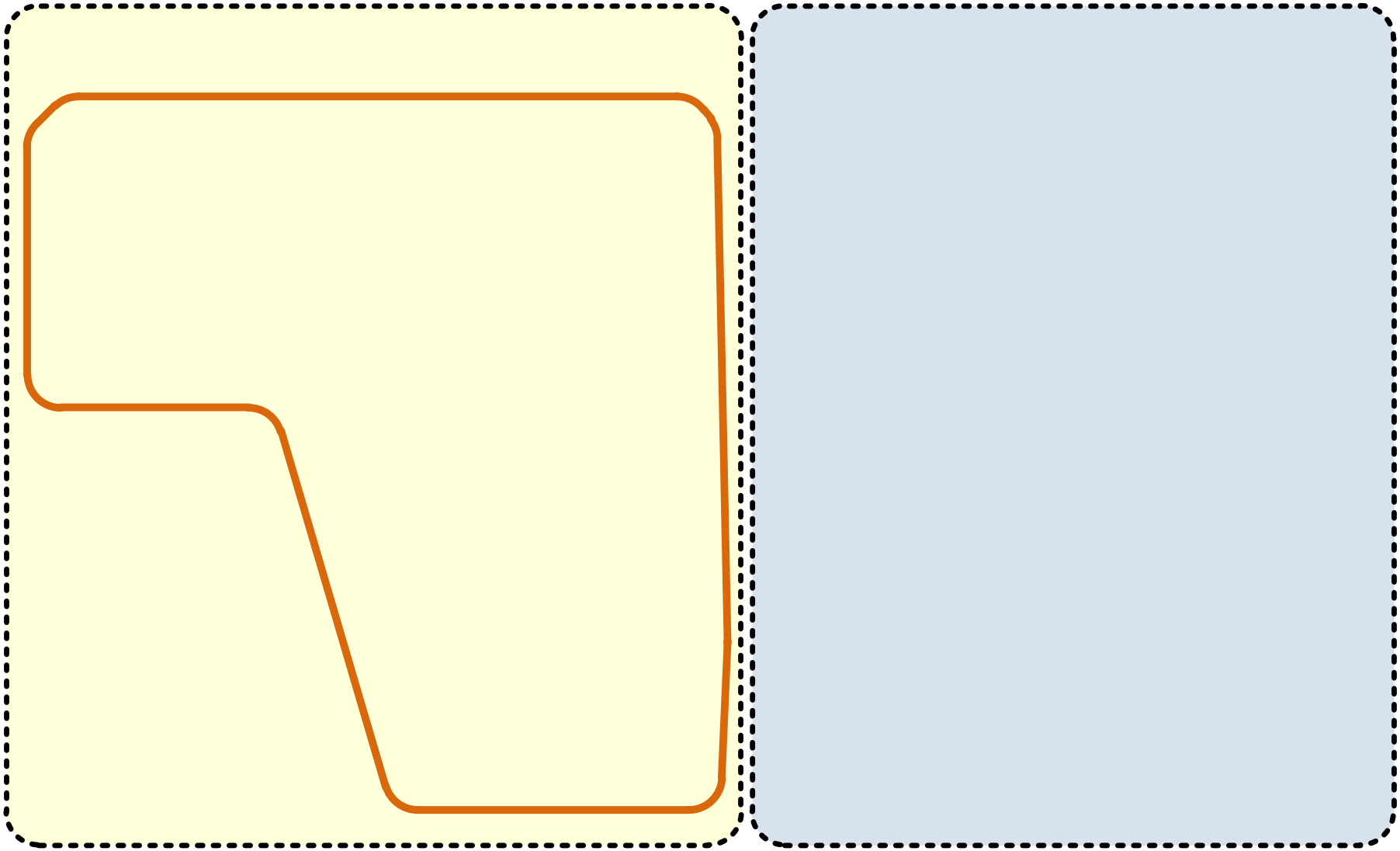
- **Research Promotion Foundation of Cyprus** (RPF, Cyprus)
- **Ministry of National Infrastructures, Energy and Water Resources** (Israel)
- **SOLAR-ERA.NET** (EU-FP7)

Development of a novel PV system architecture

- **PV inverter (*KIOS*)**
- **PV system**
- **KBSS (*Chakratec's patented storage system*)**
- **Smart Meter Management (*PowerCom*)**
- **DNMT (*Eletoyia*)**
- **Prosumer's controllable loads**



Project outline



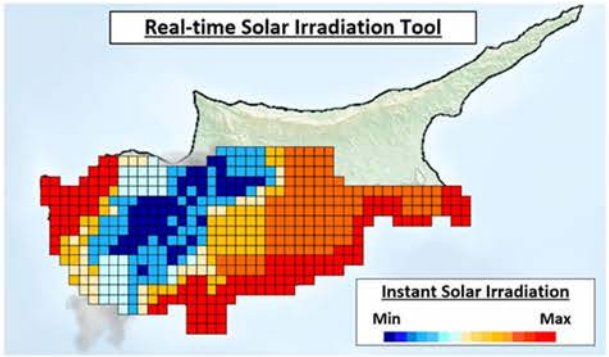
Objectives

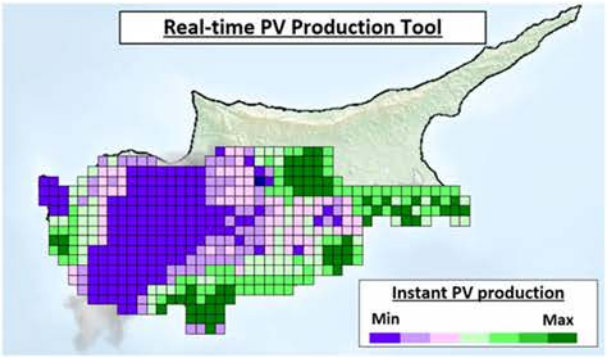
- **Seamless and massive integration of residential PV systems**
- **Enable flexible and multi-functional products**
- **Improve power system quality and stability**
  - ✓ **10% decrease of the peak demand**
  - ✓ **20-30% decrease of the prosumer's exchange power**
  - ✓ **Enable effective grid support of both frequency and voltage by the prosumer**
  - ✓ **Improved power quality (i.e., voltage and frequency management, congestion management, flexible load shedding, voltage symmetrizing, etc.)**
- **5-8% increase of the Kinetic Battery Storage System (KBSS) efficiency**
- **7-10 years extension of the inverter lifetime**
- **Low-cost monitoring of the now-casting PV production of the rooftop PVs**
- **Awareness of the distribution grid operating conditions**
- **Efficient and coordinated control of distribution grid**

KOIOS
Research and Innovation Centre of Excellence

Development of a Distribution Network Monitoring Tool

- **Use of location and weather based clustering**
- **Choice of representative PV site in each group and monitoring**
- **Upscaling techniques to estimate the aggregate power production of all the PVs in an area and the voltage operating conditions at the low voltage feeder**
- **Measurements (using the APIs of the inverter) (V, P, Q) will be concentrated every 5-15 min**
- **Results will be available in an online database**

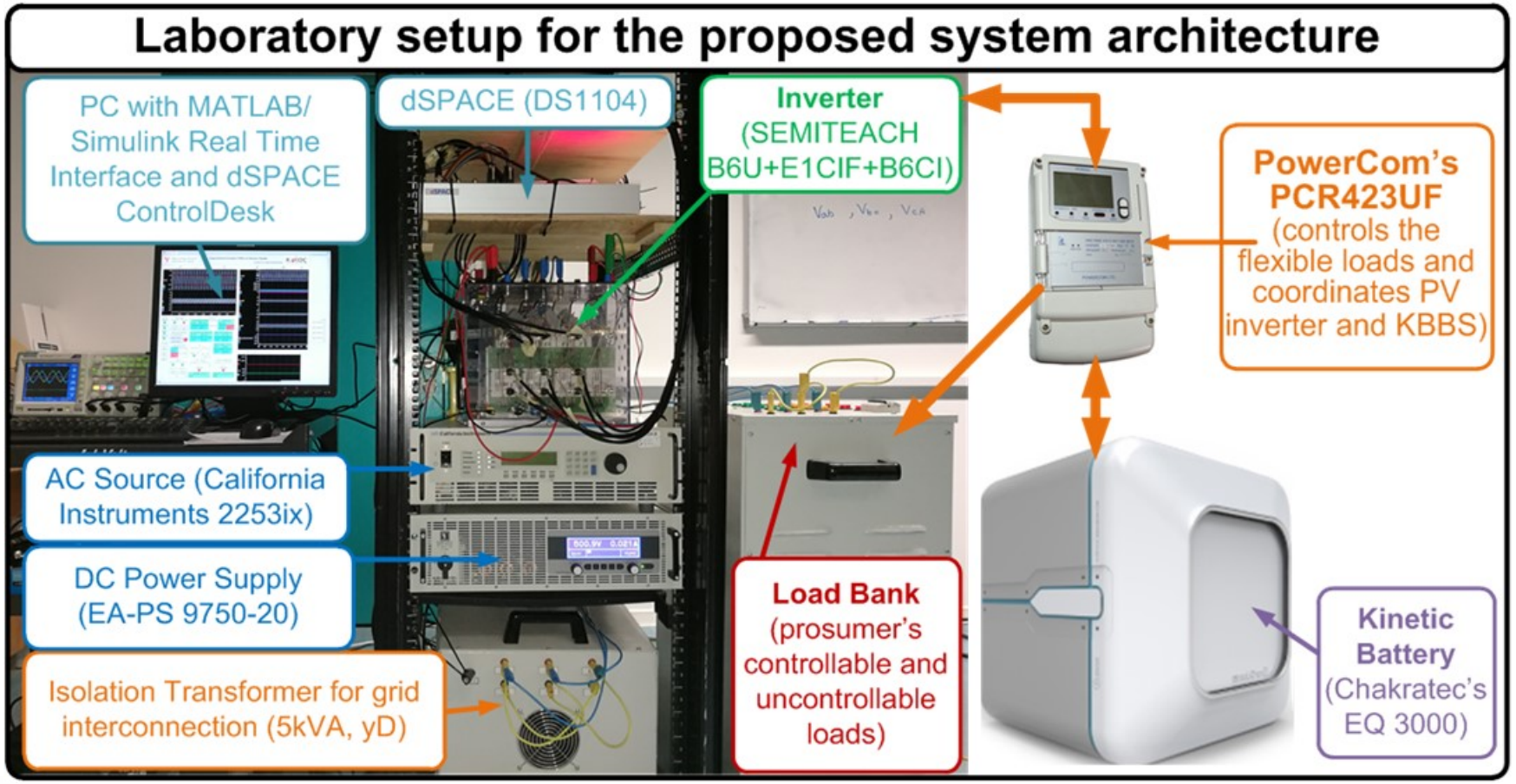




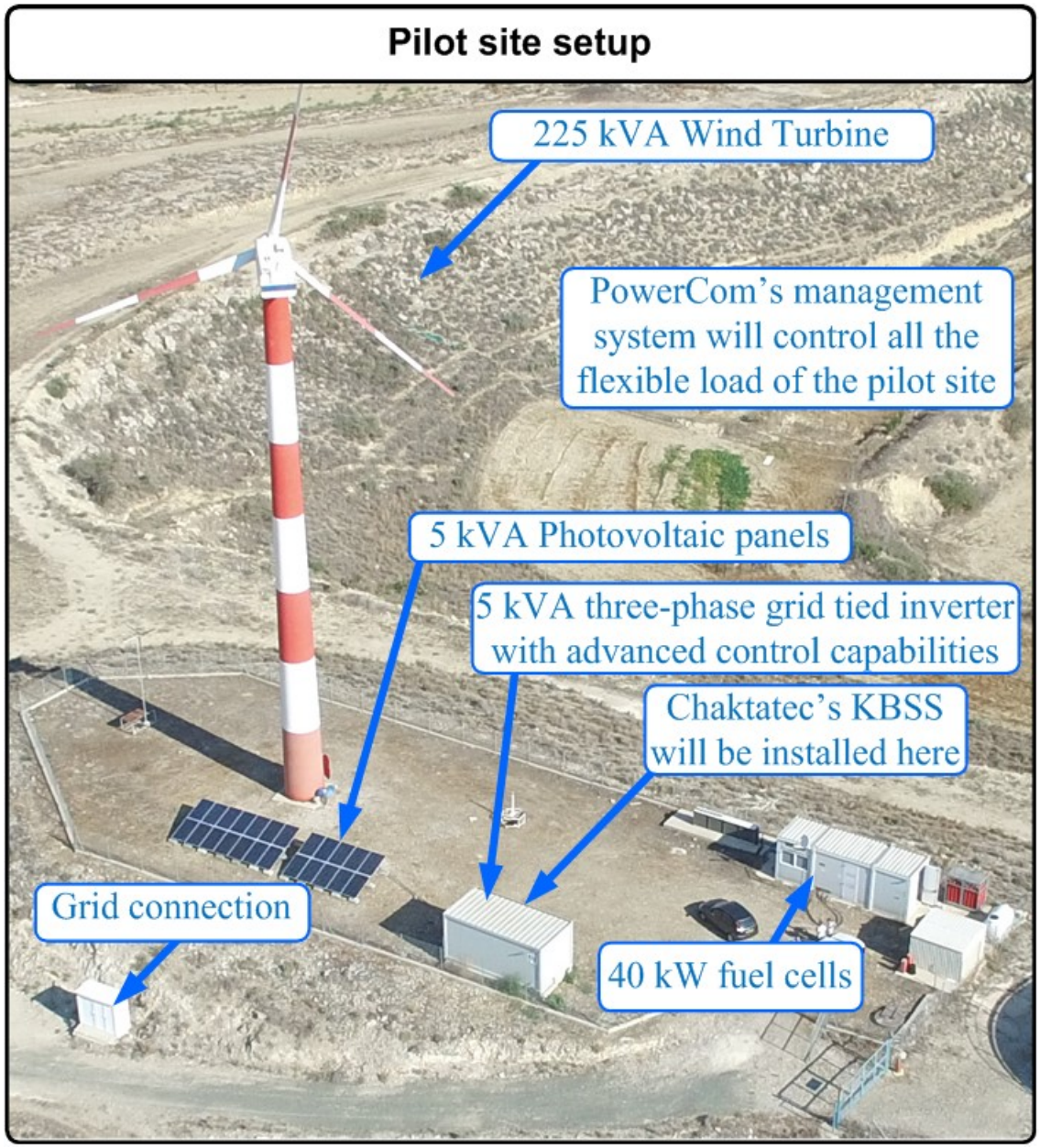
KOIOS
Research and Innovation Centre of Excellence

Prototype development and pilot testing

All concepts and methodologies will be tested and validated in both laboratory and grid-connected conditions



Prototype development and pilot testing



FLEXITRANSTORE- EU H2020

- **Title: Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables**
- **Budget: 17 million euros (KIOS share: ~1 million euro)**
- **Main objectives: develop eight large-scale pilots related to substation level storage, smart transmission lines, flexible generation units, energy market**
- **Consortium: 28 partners -- Universities, manufacturers (Schneider Electric, General Electric, Abengoa, etc), several TSOs and DSOs around Europe**

KIOS
Research and Innovation Centre of Excellence

Inverter-less connection of PVs to the grid

- **Perform the dc/ac conversion through a set of interconnected electrical machines and a custom-made patented controller => Avoid the use of conventional inverters for the dc/ac conversion (expensive, harmonics).**
- **Ability to fully control active and reactive power injection.**
- **Provision of inertia to the grid – extremely important for isolated networks.**
- **Can compensate for the variability of the dc source.**

KOIOC
Research and Innovation Centre of Excellence

Limassol, Cyprus

ENERGYCON 2018

IEEE International Energy Conference

3 - 7 June, 2018

Towards Self-healing, Resilient and Green Electric Power and Energy Systems

Thank you!

Contact: elias@ucy.ac.cy **http://www.kios.ucy.ac.cy**

SOLAR-ERA.NET

Research Promotion Foundation

KIOS Research and Innovation Centre of Excellence