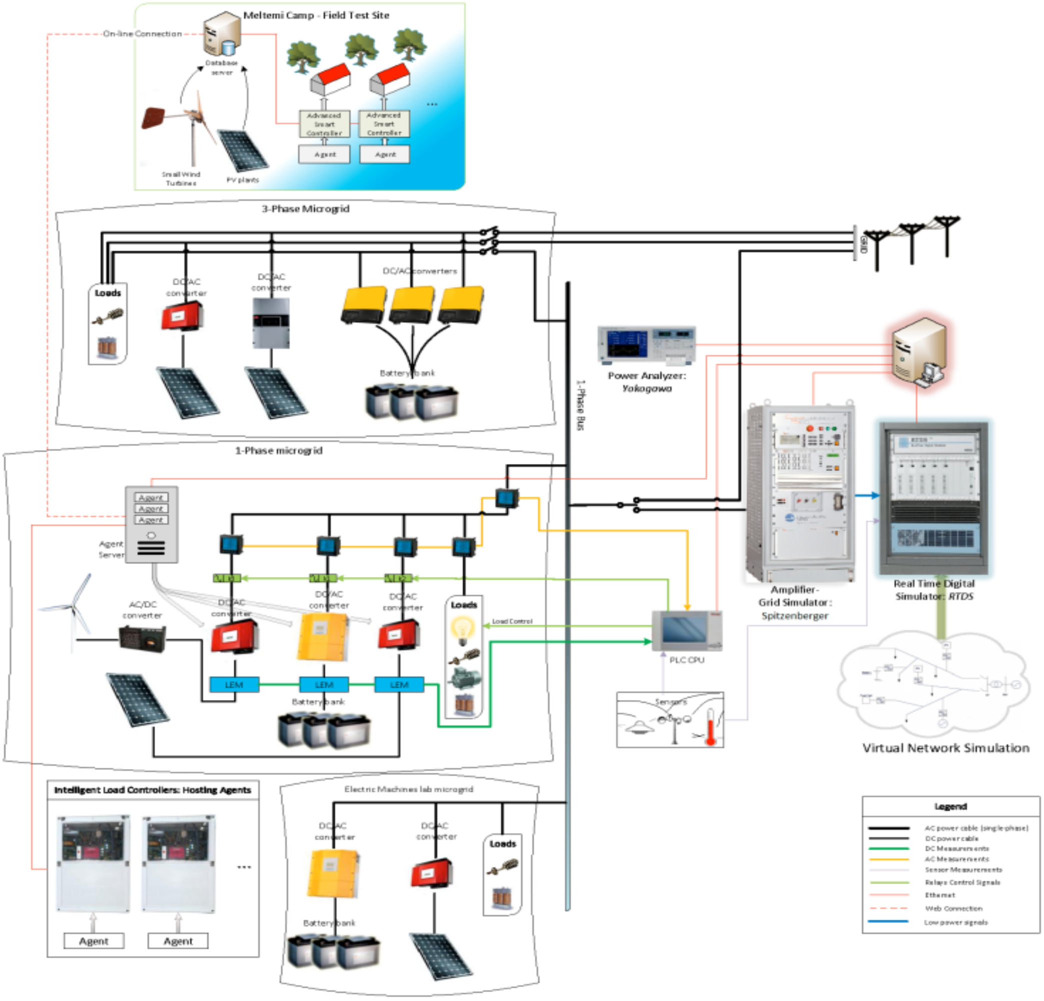
The **EESL (ELECTRIC ENERGY SYSTEMS LABORATORY)** comprises the following equipment:

- **Low Voltage Microgrid**: A main component of the laboratory is the single phase microgrid that includes a PV generator, a small Wind Turbine, battery energy storage, controllable loads and a controlled interconnection to the local LV grid. The battery unit, the PV generator and the Wind Turbine are connected to the AC grid via fast-acting DC/AC power converters. The converters are suitably controlled to permit the operation of the system either interconnected to the LV network (grid-tied), or in stand-alone (island) mode, with a seamless transfer from the one mode to the other. Part of the laboratory's infrastructure is the 3-phase microgrid with main elements 3 single-phase battery inverters and micro-sources connected in each phase.

- **Multi-Microgrids Cluster**: The three ICCS-NTUA Microgrids form a Multi-Microgrid cluster (through Electrical and Internet connection) in order to investigate the development and verification of different control strategies and the impact of wide deployment of Microgrids at the distribution level.

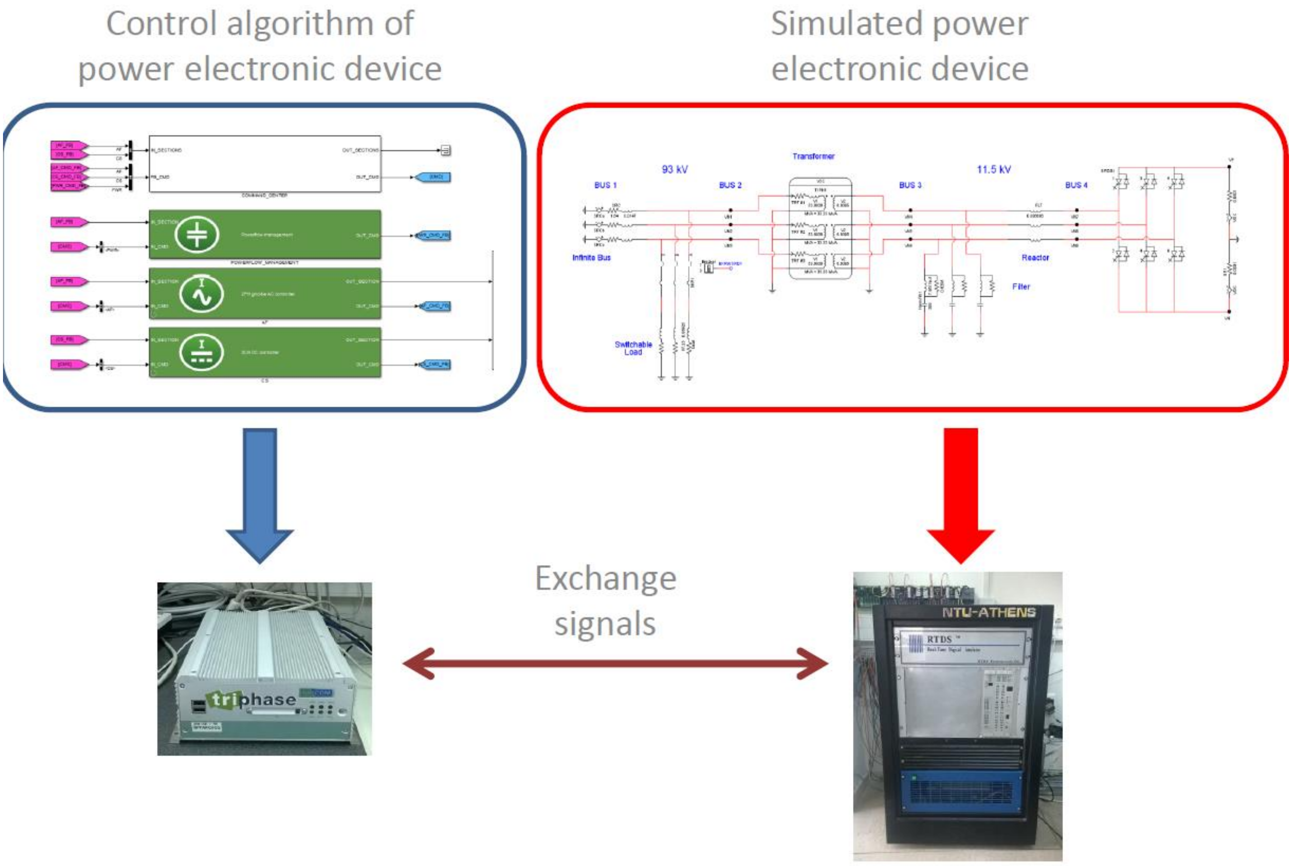
- **Multi-Agent System for Microgrid Operation***:* Multi-agent technology has been implemented for the control of the distributed sources and the loads of the LV microgrid. The system is developed in the Java based platform called Jade and communicates with the DER/DGs via industrial communication protocols such as OPC. Furthermore the laboratory is equipped with 10 load controllers. These are embedded systems with Java Virtual Machine, multiple analogue & digital I/O as well TCP/IP connectivity. This system can be used to test in the laboratory or in a real test field various algorithms for distributed control of Microgrids and DG/RES. Some of the functionalities that can be tested are: market participation of the Loads or the DG/RES, formulation of a VPP, ancillary services provision, black start operation, islanded operation, multi-Microgrid operation and emergency load shedding.

- **Laboratory SCADA**: The laboratory SCADA is implemented using a PLC (Programmable Logic Controller) system with LabVIEW/CoDeSys software. It provides measurements on the AC and DC side of the inverters, environmental measurements (irradiation, wind speed etc.), control of the DGs and load profile programming.

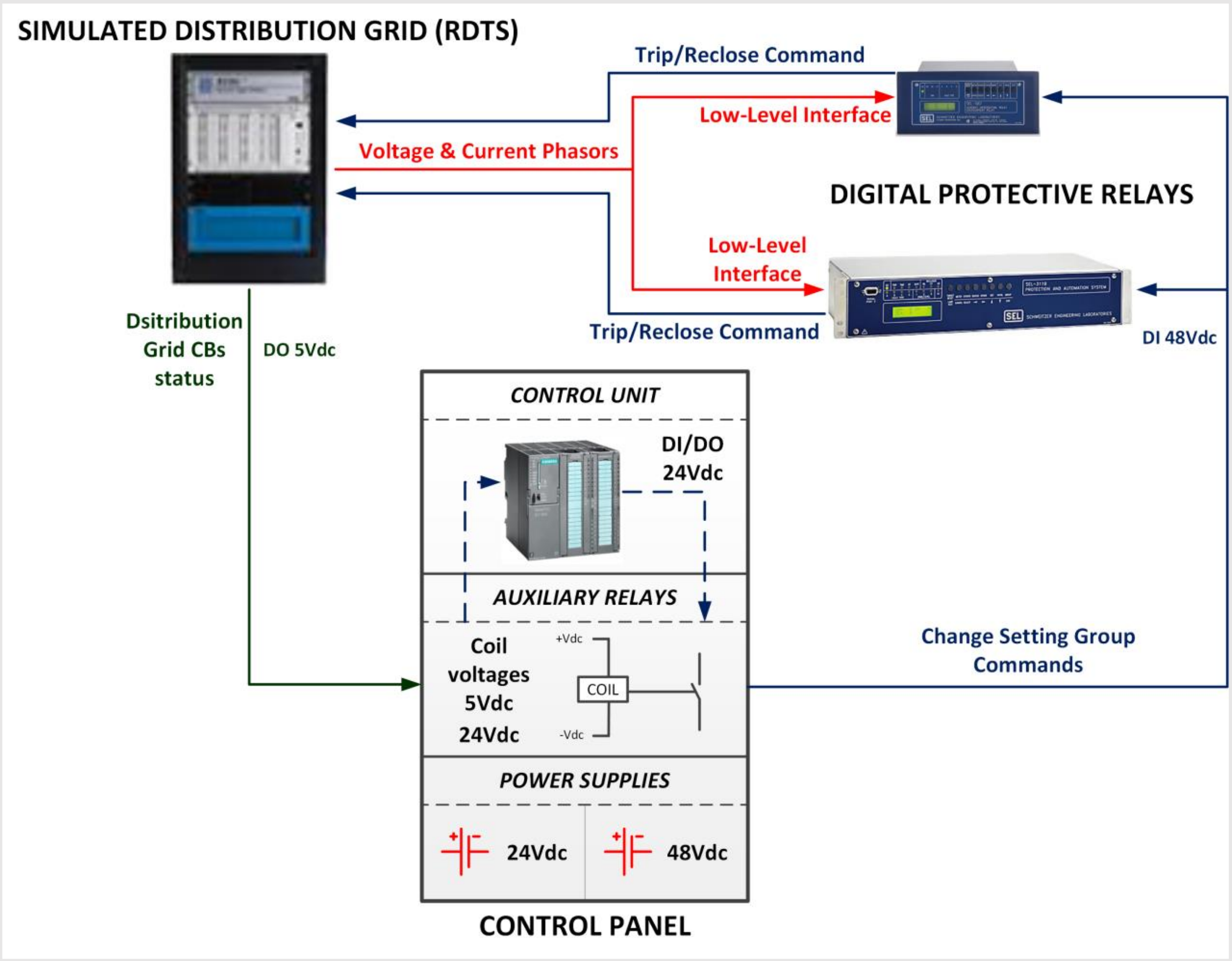

Meltemi Camp - Field Test Site
On-line Connection
Database server
Advanced Smart Controller
Agent
Small Wind Turbines
PV plants
3-Phase Microgrid
Loads
DC/AC converter
DC/AC converters
Battery bank
GRID
1-Phase Bus
Power Analyzer: Yokogowa
1-Phase microgrid
Agent
Agent Server
AC/DC converter
LEM
Load Control
PLC CPU
Sensors
Amplifier-Grid Simulator: Spitzenberger
Real Time Digital Simulator: RTDS
Virtual Network Simulation
Intelligent Load Controllers: Hosting Agents
Electric Machines lab microgrid
Legend
A/C power cable (single-phase)
DC power cable
DC Measurements
A/C Measurements
Sensor Measurements
Relays Control Signals
Ethernet
Web Connection
Low power signals

- **Power Hardware-in-the-Loop (PHIL) simulation environment**: The PHIL facility developed at ICCS-NTUA provides an efficient environment for studying interactions between hardware DER power devices and various simulated networks. A rack of the commercially available Real Time Digital Simulator RTDS® is operated. A Switched-Mode Amplifier by Triphase and a linear amplifier by Spitzenberger & Spies (PAS 5000) are used as a Power Interfaces between the RTDS and physical equipment to perform PHIL simulation. The Triphase power electronic converter platform allows the user to design in Matlab/Simulink the control algorithms. PHIL experiments are performed, where hardware equipment (loads, PV inverters, etc) are connected to simulated distribution networks. An irradiation sensor and an anemometer, provide input to simulated models in the RTDS in order to achieve realistic conditions.

- **Controller Hardware in the Loop (CHIL) simulation environment:** In the context of its involvement with microgrids and dispersed generation, the research group is active in the development and study of advanced control algorithms for power electronic converters (DC/DC, DC/AC, AC/DC/AC, etc.). Based on the real-time simulator (RTDS) and a controller provided by Triphase, it is possible to thoroughly test control algorithms of power converters in an environment that reveals "hidden" weaknesses and faults in the design of these algorithms. Specifically, the design of the control algorithm is performed in the controller of Triphase while the power electronics are simulated in the RTDS. The communication between the two systems is achieved through analog and digital signals.



- **Adaptive Protection System in Distribution Grids with DER Penetration in a HIL environment:** In order to study new protection problems arising, a laboratory adaptive protection system has been developed at ICCS-NTUA. The electrical networks are designed and studied in the real-time digital simulator (RTDS). Through analogue and digital signals the RTDS is connected to external devices, such as the industrial protection relay SEL-311B. The relay is programmed to protect a feeder of the electrical network and receive voltage and current signals from the RTDS. It also controls the status of the simulated breaker in the RTDS while its condition is fed back to the relay. All relays have overcurrent elements with 2-6 setting groups that are used for the adaptive protection implementation.

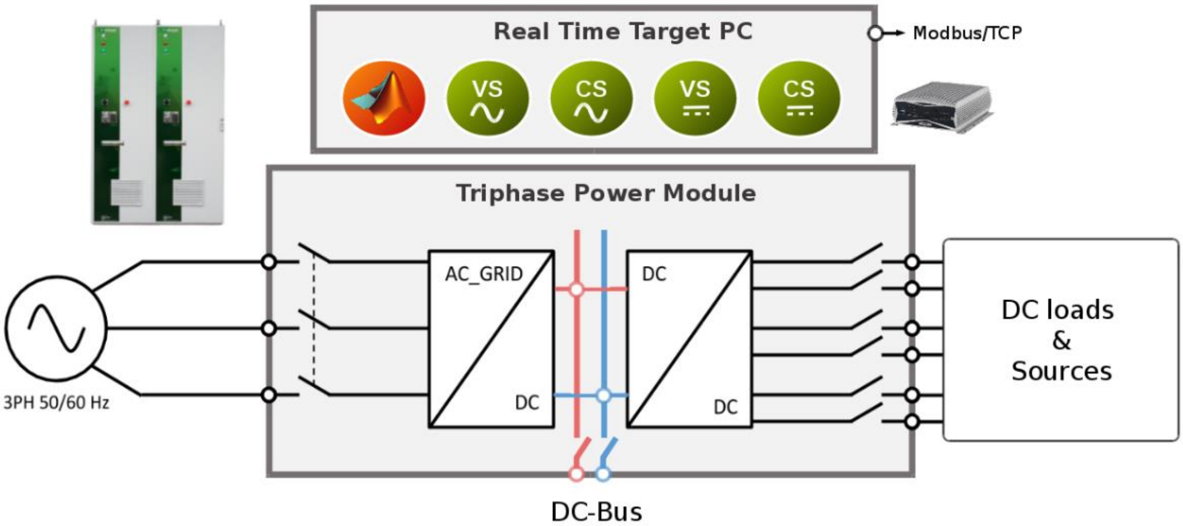


- **PV Inverter testing according to standards**: The laboratory operates the necessary equipment to perform tests on photovoltaic inverters according to standards. A PV Simulator by Regatron (3x TopCon Quadro Programmable DC Power Supply) features fully controllable and customizable voltage-current characteristics (V-I), and a Linear Amplifier/Grid Simulator by Spitzenberger & Spies (PAS 5000 – 4 Quadrant Linear Amplifier 5kVA) applies voltage (dips, introduction of harmonics etc) and frequency variations on the inverter. In this way a testing environment is created for the testing of both the direct current (DC) and alternating current (AC) side of the inverter. By appropriately controlling the two simulators, the necessary conditions specified by the standards for PV inverter tests are represented. The tests that can be carried out in the laboratory are:

    - Static and Dynamic Maximum Power Point Tracking (MPPT) (EN 50530)
    - EMC tests (IEC 61000-3-2, Harmonic measurements 0-100KHz, etc.)
    - Connection requirements (VDE-AR-N 4105)
    - Fault ride through (VDE 0126-1-1)
    - Anti-islanding Requirements (In progress)

  The electrical quantities (voltage, current, power, etc.) during the tests can be measured accurately and analyzed with the use of a Yokogawa WT3000 Power Analyzer.

- **Flexible Power Electronics Configuration for Coupling RES & Storage:** At EESL the simulation of distribution network under future scenarios is thoroughly analysed. An integral part of this process are the Triphase's Distributed Power Modules that realize a scalable, flexible and open platform for rapid prototyping of power conversion and power system applications. The setup consists of a 15 kVA bidirectional active frontend (DC/AC), and a 15 kW bidirectional DC/DC converter consisting of 3 channels. The Power Modules are fully reconfigurable and open. Researchers have access to all data and can change all the software (based on Matlab/Simulink) from the highest level (e.g. coordination and control of power flows between the storage and the grid) down to the lowest level (e.g. PWM control). Currently the module is operated as a 3ph inverter to interface a battery storage system or as a 1ph-3-leg back to back converter (AC/DC/AC) for power amplification. All converters are connected to a single DC bus which is accessible to external DC sources (e.g. Dc simulator). The open, reconfigurable and fully reprogrammable structure of the Power Modules can readily be adapted to new research areas.



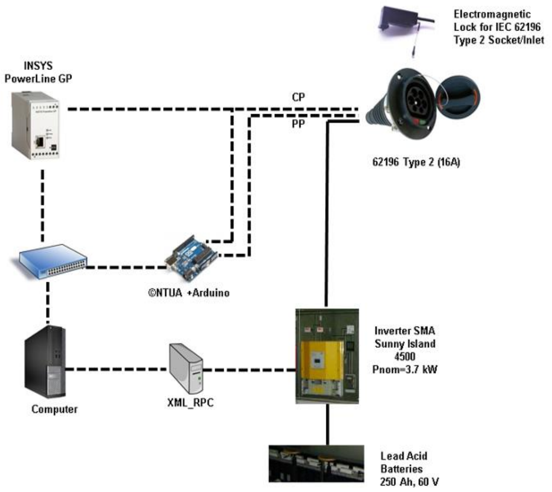
- **Axial flux generator bench testing facilities**: The bench testing rig allows for the testing of axial flux generators of power up to 9kW and maximum diameter of up to 1m. With the use of a 60 HP DC motor, a DC bi-directional drive and a tachogenerator, the axial flux generators can be driven at different and constant revolutions per minute (RPM). Different loads can be applied to the generators such as a grid-tie inverter for grid connection or a 12/24/48V battery bank for battery charging modes, along with a diversion load controller and resistive load. In addition, a three phase ohmic load of maximum power 3.3kW can be connected directly to the generator. The experimental setup mentioned allows for a complete analysis of the generator's behavior under different situations.

- **Residential Wind and Hydro Turbines construction***:* The study and simulation of residential wind and hydro turbines for rural electrification applications follows local manufacturing which enables the user with the ability of local maintenance and immediate repairs of possible failures. In the workshop, small wind and hydro turbines are constructed from scratch. Up until now, residential wind turbines for battery charging and grid connection have been manufactured, with rotor diameters of up to 4.3 meters and a pico-hydro system of 500W.

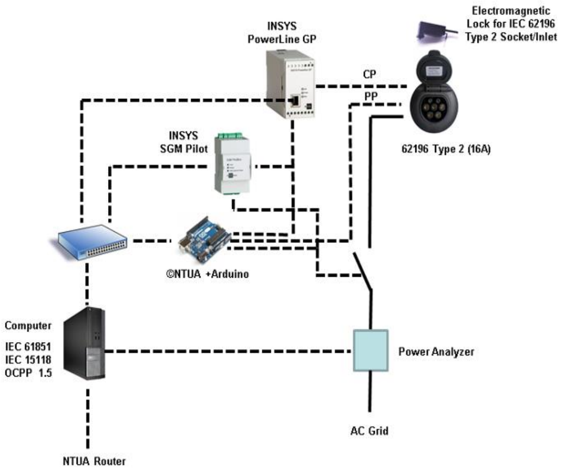
- **E mobility lab facilities:**

  The lab facilities which can be exploited for e-mobility applications are:

  - An **EV (Electric Vehicle) emulator** supporting the interoperability testing of the EV related protocols (IEC61851) is developed. It can be connected to an EVSE (Electric Vehicle Supply Equipment), as the device under testing, in order to validate its compliance with the standards.
  - An **EVSE emulator** allowing the charging of a real or emulated EV in respect to IEC61851. The EVSE can also communicate with external stakeholders, i.e. the EVSEO, implementing the OCPP 1.5 protocol. Apart from the EVSE emulator, a commercial EV charging station (ETREL wallbox- 32A) is also available with smart charging capabilities.
  - An **EVSEO (Electric Vehicle Supply Equipment Operator)** adopting the OCPP 1.5 protocol for the communication with custom-made or commercial EVSE.
  - **A custom-made energy management system with user interface** offering several services to e-mobility stakeholders such as searching for EVSE location, electricity price information, EVSE availability, booking capabilities. The interaction between the EV user interface and the EVSEO is realized via Rest-Based Web Service technology.



EV emulator



EVSE emulator