Research and Teaching Facilities at Faculty of Engineering, HIOF

Intelligent Control of Energy Conversion and Storage Systems

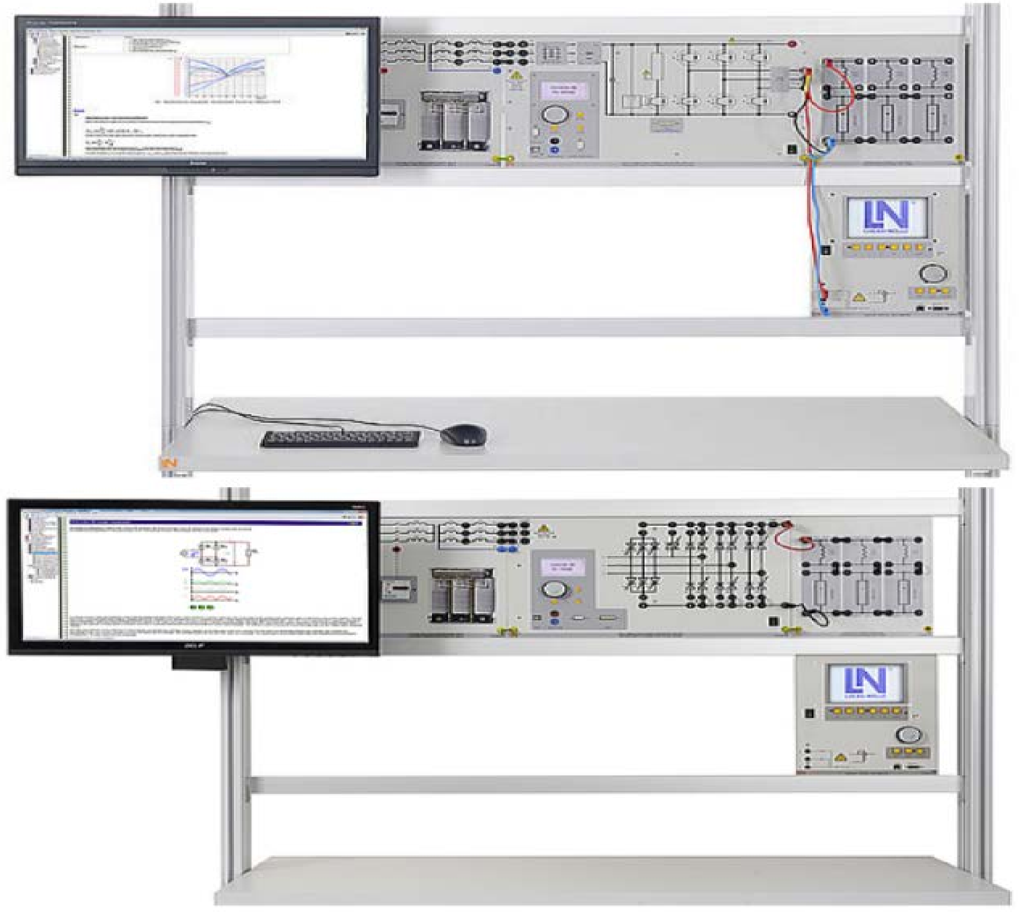
Professor Dr. Eng. Lucian MIHET

Intelligent Control of Energy Conversion and Storage Systems Laboratory – S403

- The lab is dedicated for teaching and research in connection with Master Program “Green Energy Technology”, but can also be use by Bachelor and PhD students with electrical, electronics and computer science specializations.
- The lab is equipped with state-of-the-art and new technology (software and hardware) regarding electric power engineering, power electronics, renewable power generation and Smart Grids;
- Training systems on the generation, distribution and management of electrical energy contains smart measuring instruments, which avail of various communication interfaces (e.g. LAN, RS485, USB) and control elements: SCADA Power Engineering Lab software tools for the intelligent control and evaluation of the "Smart Grid" with soft PLC. Didactically designed SCADA software permits investigation of dynamically alternating loads and power generation inside the laboratory, intelligent energy management, and modular integration of renewable energies into the smart grid using protective engineering, wind power plant with doubly-fed asynchronous/induction generator (DFIG) with mains synchronization and interactive multimedia training course.

Setups and trainers

- It contains 10 setups/trainers with Renewable Energy Sources (PV, WT), Storage Systems and Power Electronics Converters for Electric Drives applications, Energy Efficiency in Smart Buildings and Smart Grids, as it is shown in Figs below.



Professional Photovoltaic Trainer

- This solar trainer allows the passage of the sun to be simulated realistically. This makes it possible to conduct experiments in the lab in practical fashion without any need for the sun itself. The design of photovoltaic systems operating in parallel with the electric power grid is realistic. In order to stabilize the electricity grid, the techniques of derating the power inverter and controllable local transformers are used. Knowledge and practical skills along with computer-based assessment of measured data are made possible by the professional photovoltaics multimedia course along with SCADA Power Lab software and MATLAB-Simulink.

Profesional Photovoltaic Hybrid System

Intelligent Control of Energy Conversion and Storage Systems

Faculty of Engineering – Østfold University College

Østfold University College
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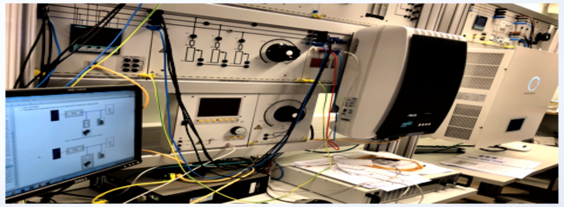
INTRODUCTION

This solar trainer allows the passage of the sun to be simulated realistically. This makes it possible to conduct experiments in the lab in practical fashion without any need for the sun itself. The design of photovoltaic systems operating in parallel with the electric power grid is realistic. In order to stabilize the electricity grid, the techniques of derating the power inverter and controllable local transformers are used.

Knowledge and practical skills along with computer-based assessment of measured data are made possible by the professional photovoltaics multimedia course along with *SCADA Power Lab* software.

The design of photovoltaic systems connected to the grid is realistically conveyed. In order to stabilize the power grid, techniques such as de-rating the inverter power and a variable local network power transformer are employed.

This setup is able to work in conjunction with the BESS Setup in order to conform an hybrid solution with an energy storage system, allowing the study of the relationship of this solution with the grid and the influence of load variations



OBJECTIVES OF THE SETUP

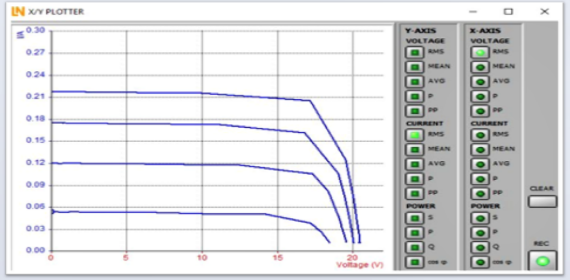
- Recording of module response over days and years
- Testing optimum alignment of solar modules
- Recording characteristics of solar modules
- Set-up and testing of a photovoltaic system with feed to the power grid
- Measurement of energy generated by photovoltaic systems
- Maximum Power Point (MPP) Tracking
- Limiting the power of the photovoltaic inverter (derating)
- Configuring the invertir for reactive power provision
- Determining the efficiency of the power grid inverter
- Response to control of the power grid inverter
- Recording output data using sun passage emulator
- Investigating the response of a photovoltaic system when there is a power outage on the grid
- Lightning protecting for photovoltaic systems
- Economic benefits of photovoltaic systems
- Use of a local-area network transformer for automatic voltaje control in a smart grid
- Operation and monitoring using SCADA
- Design and installation of the battery storage unit
- Putting the storage unit into operation
- Interaction between PV systems and storage units
- Boosting intrinsic consumption thanks to energy storage units

EXPERIMENTS

Recording panel characteristic

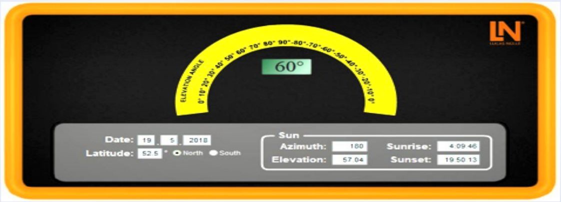
Between the two operating points representing open-circuit and short-circuit respectively, it is possible to measure further operating points at different currents. All measurement points together result in the V/I characteristic. This characteristic is determined by measuring the solar module's currents and corresponding voltages. A variable load resistor (potentiometer) is connected in order to set different measurement points..

For this experiment the solar panel with halogen lamp is connected in series with the potentiometer, by rotating it the V/I characteristic is recorded.



Recording annual irradiance

With the assistance of a software tool, the solar panel is positioned in a specific way depending on the input given, in this experiment the student has to record the irradiance during different days and hours in a year.

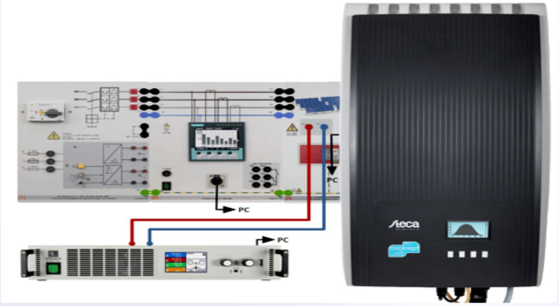


By answering a test developed in the software, the student has to prove that has understood the nature of solar irradiance during the year and the influence of latitude and panel position in the output power pf a PV plant.

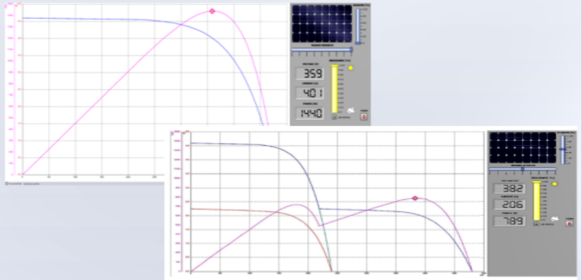
EXPERIMENTS

MPPT Tracking with and without shadings

In this experiment, the user connects the solar panel emulator to the inverter, an this one to the grid. With the software tool *Solar Panel* the emulator can be controlled.

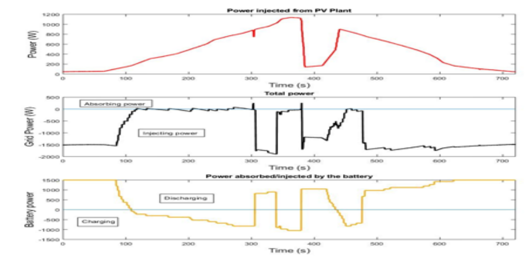


After waiting for the device to be synchronized with the grid, the user can change the irradiance and see hot the device tries to locate the maximum power point of operation.



Exchange of energy between the Li-ion battery system and the PV system with the power grid

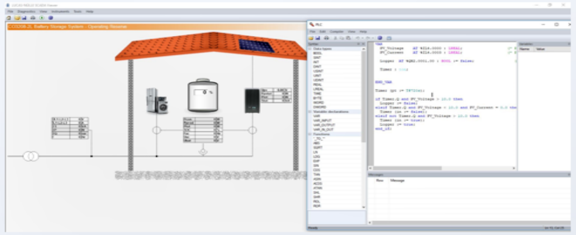
In this experiment, the user controls the battery and the PV system with the help of the *SCADA Viewer* software, by modifying the battery energy output the system can be injecting power in the grid when the PV system is unable to, in the next plot the result of the experiment is shown:



EXPERIMENTS

Monitoring of the operational reserve of a BESS in a standalone system with variable loads by using a SCADA system with a soft PLC

This experiment introduces the student to the concept of SCADA system and PLC by implementing this controller on the scenario of a house with solar panels.



By controlling the potentiometer that conforms a variable load, the student con monitor the response of the controller by providing energy from the battery or charging it depending on the balance between the demand of the battery and the power generated by the PV panels.

CONCLUSIONS

Using this setup is possible to learn the different processes that take part in a PV system, from power generation to grid connection. The theoretical course included with this setup shows the student how to dispose the modules and align them depending on the required power output and the available irradiance.

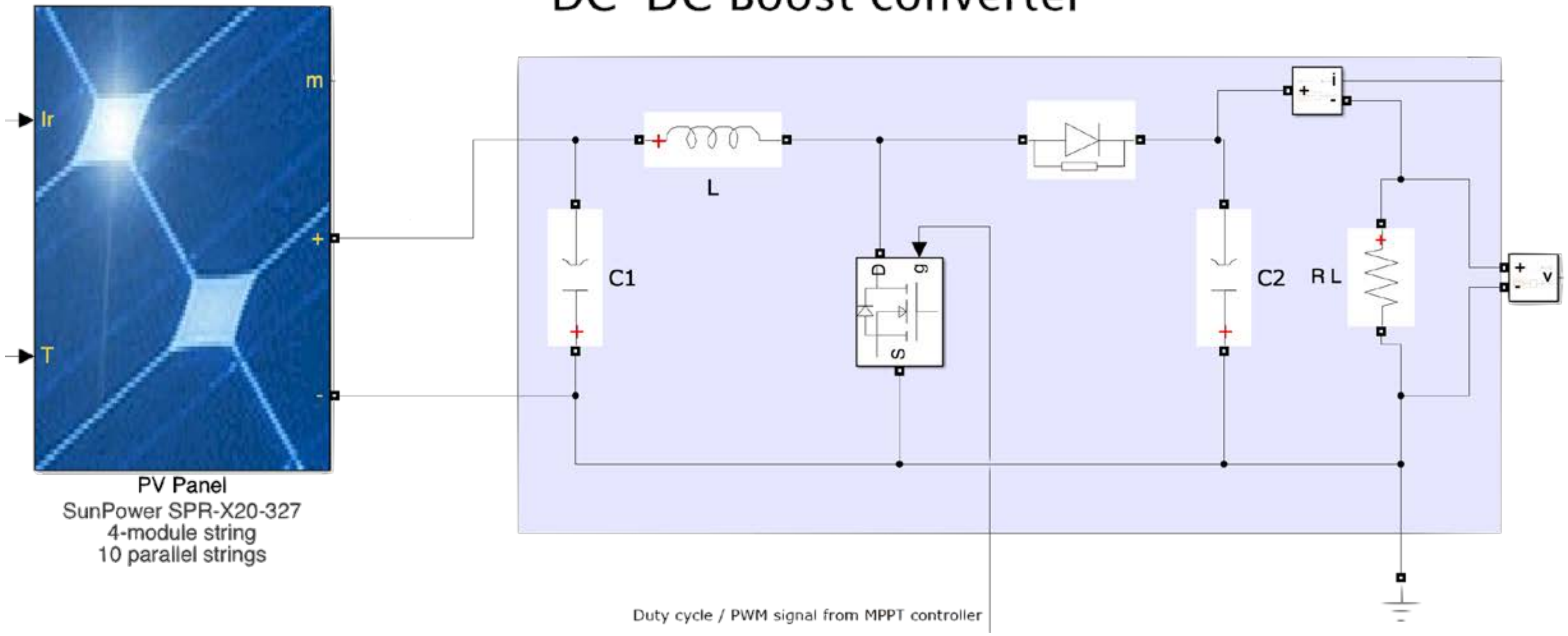
Further experiments with the SCADA software included with the setup connect the PV plant with the *Smart Grid* concept by controlling a local network transformer or regulating the power output by manipulating the inverter.

The included BESS setup introduces the student to the hybrid solution of PV with a storage system and the range of applications that the implementation of the battery opens to a PV system, including a Smart Home.

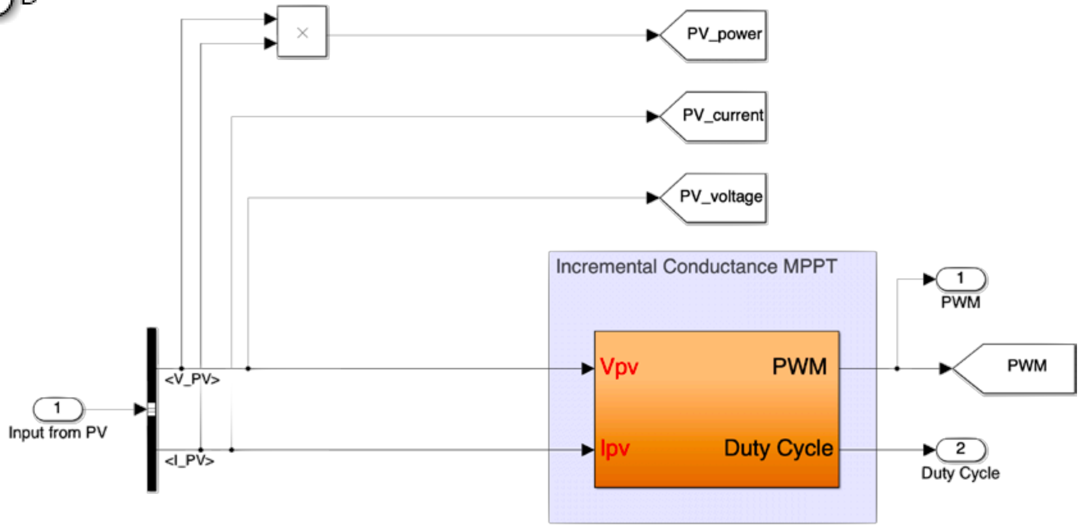
Perturb & Observe MPPT

```
>> %Perturb & Observe MPPT Algorithm

function D = po_mppt(PV_V, PV_I)

persistent Dprev Pprev Vprev

if (isempty(Dprev))
   Dprev = 0.4;
   Pprev = 0;
   Vprev = 0;
end

DeltaD = 0.05;

%Input
V = PV_V;
I = PV_I;

%Calculating power
P = V*I;

if (P - Pprev) ~= 0 % Check for changes
    if (P - Pprev) > 0 %%% Check whitch direction of change
        if (V - Vprev) > 0
            D = Dprev + DeltaD;
        else
            D = Dprev - DeltaD;
        end
    else
        if (V - Vprev) > 0
            D = Dprev - DeltaD;
        else
            D = Dprev + DeltaD;
        end
    end

else D = Dprev;
end

%Update values
Dprev = D;
Vprev = V;
Pprev = P;
```

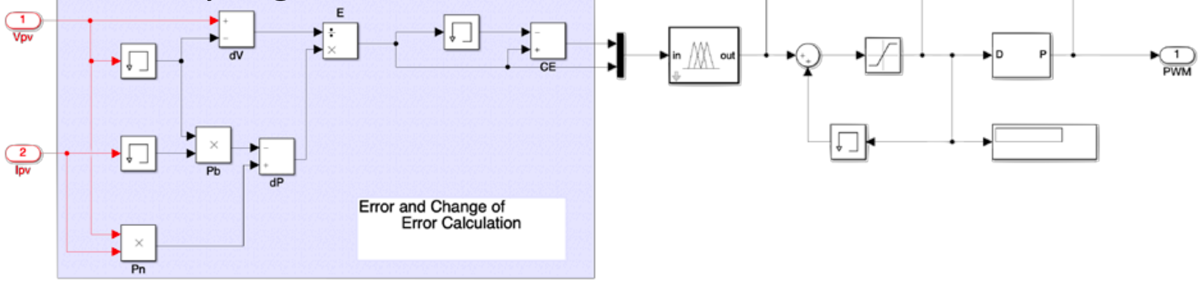
DC–DC Boost converter

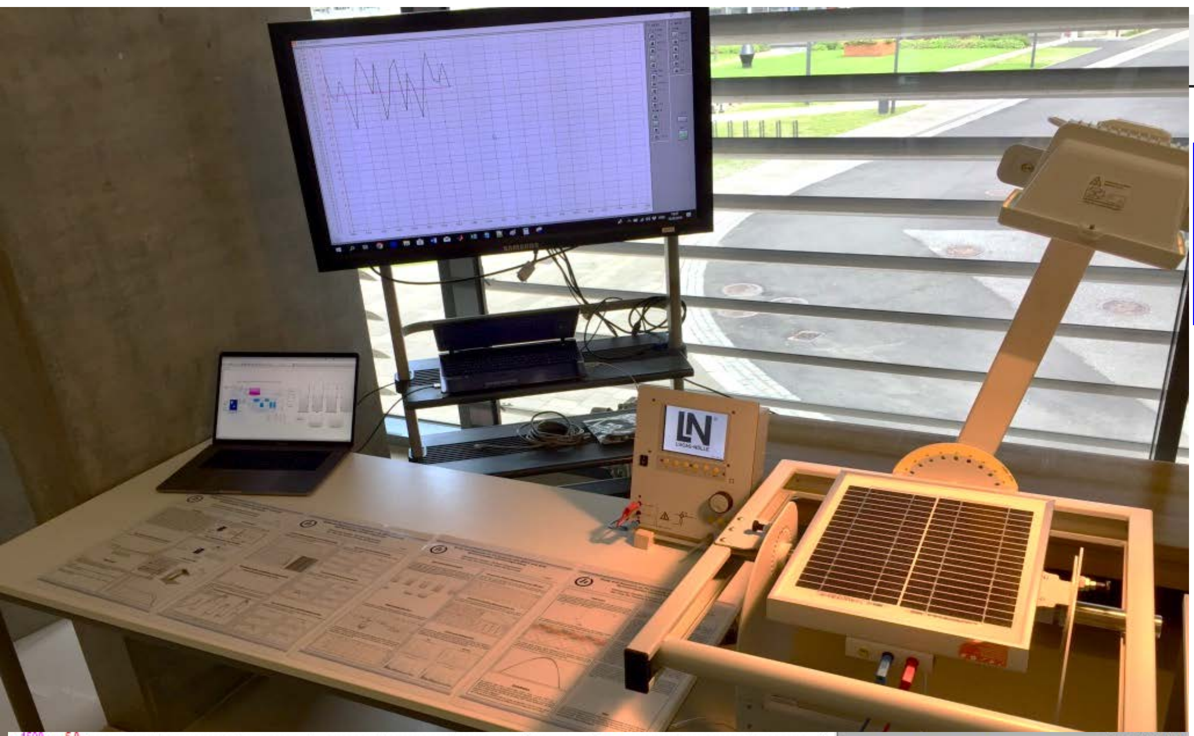


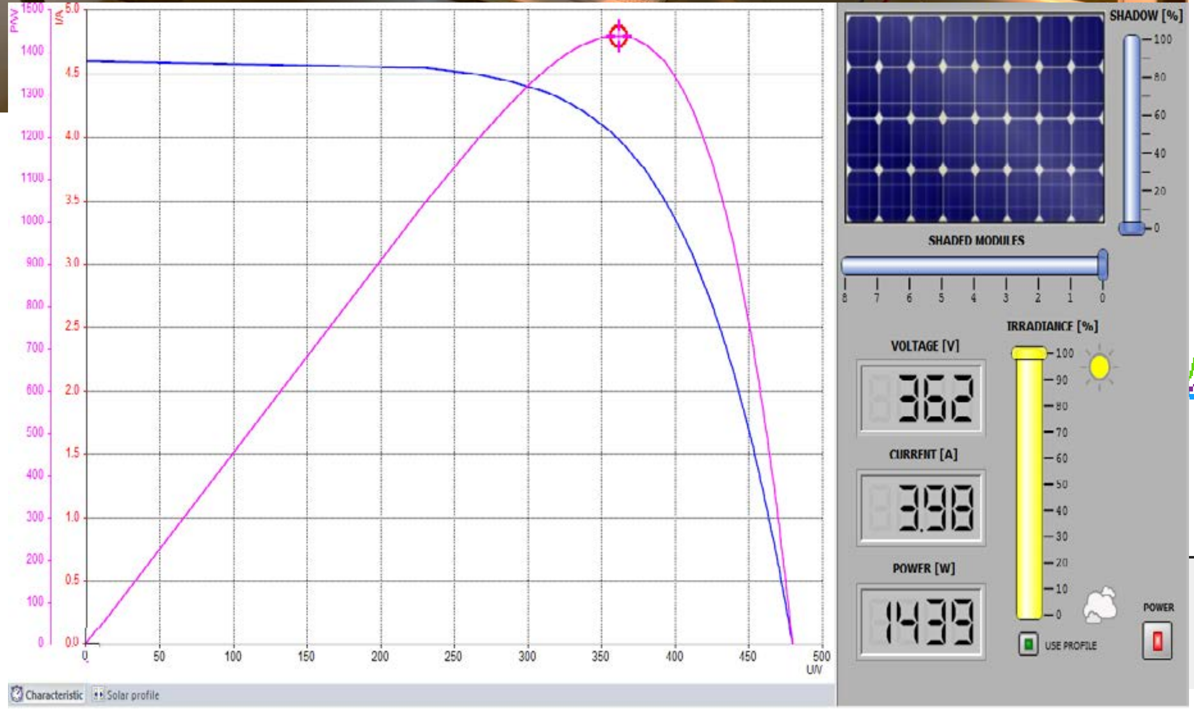
Incremental Conductance MPPT



Fuzzy logic MPPT






P/W
I/A
U/V
SHADOW [%]
SHADED MODULES
IRRADIANCE [%]
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362
CURRENT [A]
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POWER [W]
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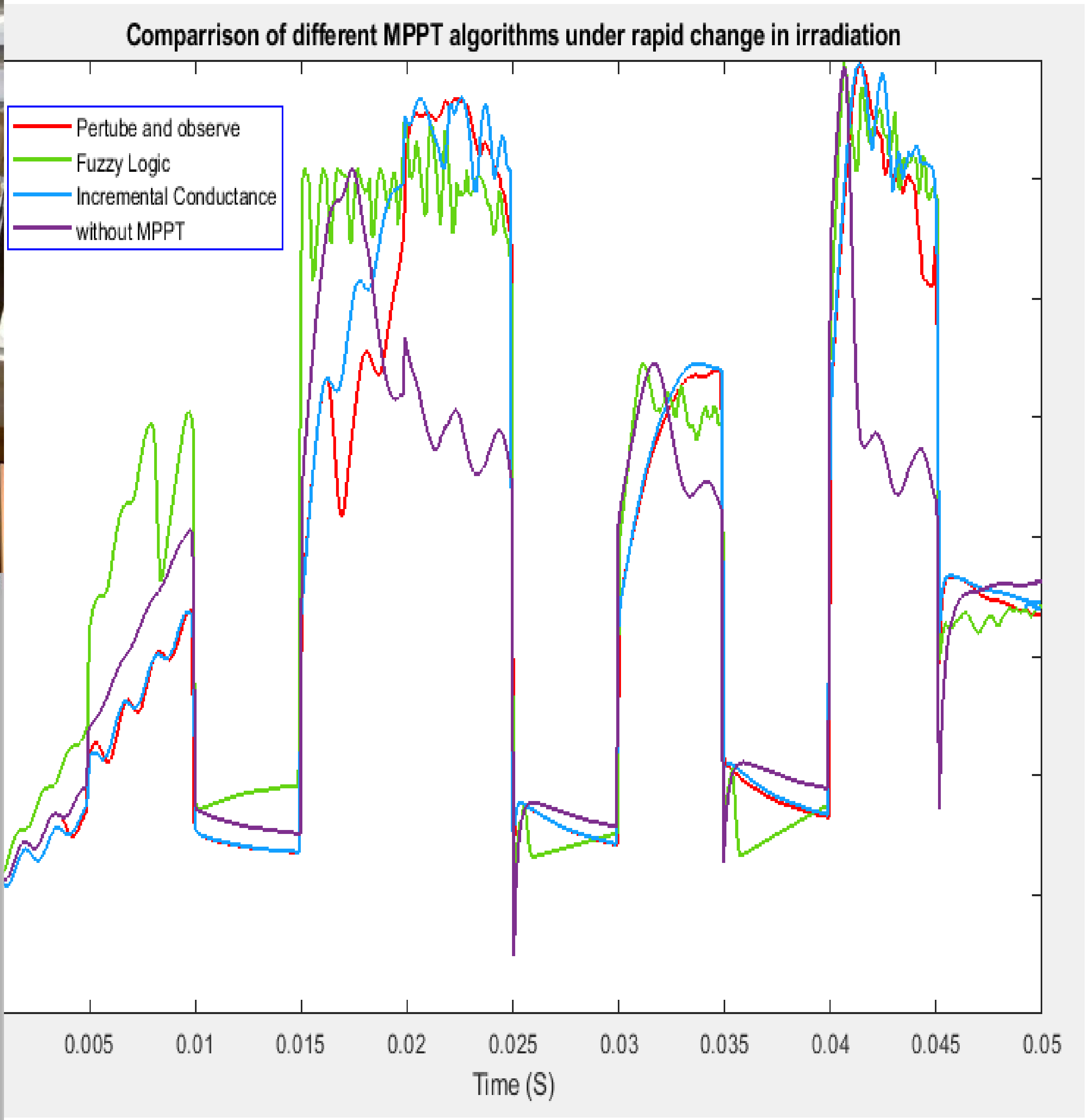
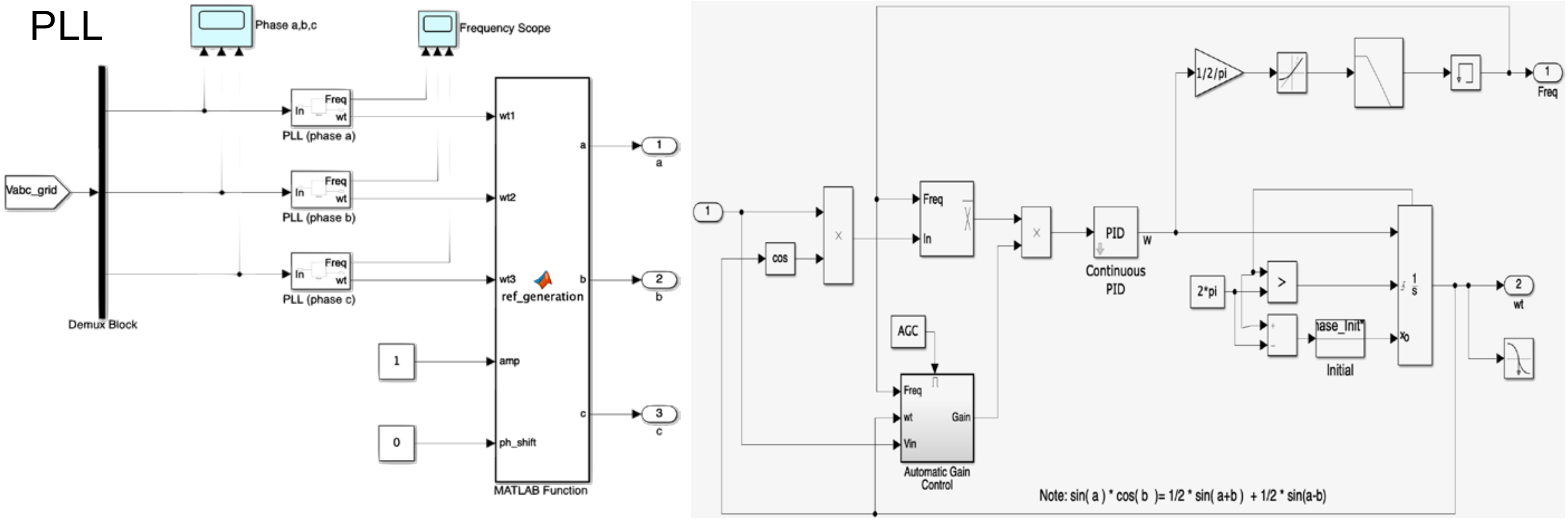
USE PROFILE
POWER
Characteristic
Solar profile


Comparrison of different MPPT algorithms under rapid change in irradiation
Pertube and observe
Fuzzy Logic
Incremental Conductance
without MPPT
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time (S)

Conventional Phase Locked Loop & Synchronous Rotating Reference Frame PLL implemented in MATLAB-Simulink

PLL



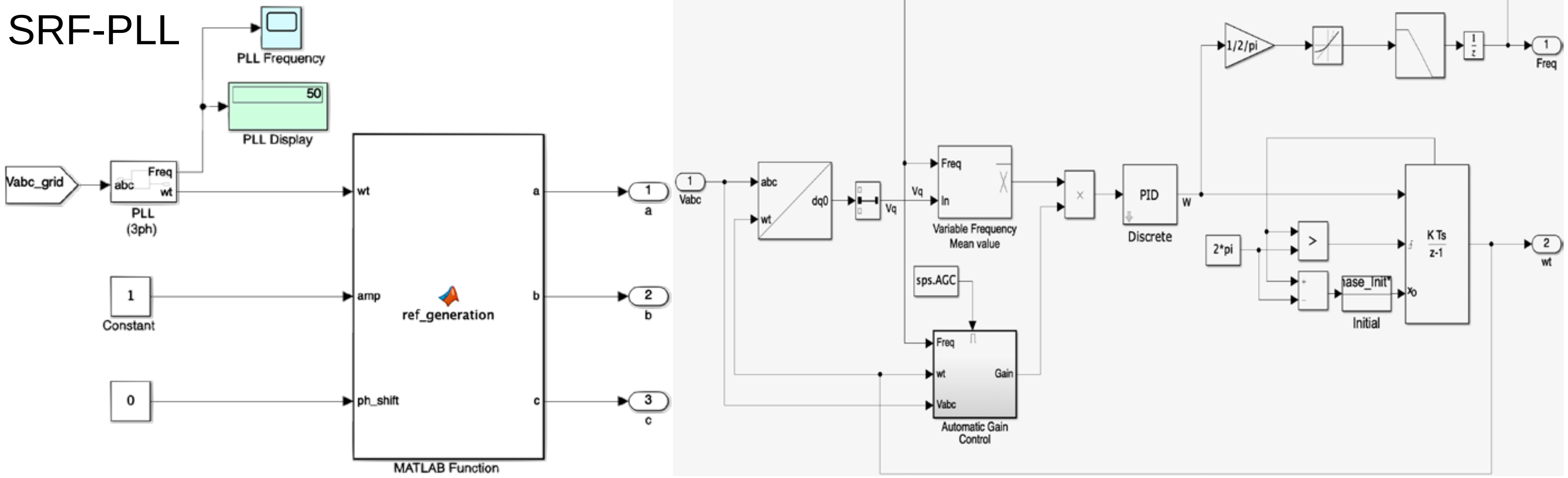
Control Systems/IGBT Control/Basic PLL/MATLAB Function*

```matlab
function[a,b,c]=ref_generation(wt1,wt2,wt3,amp,ph_shift)

shift_k = ph_shift * (pi/180);
a = amp * sin(wt1 + shift_k)
b = amp * sin(wt2 + shift_k)
c = amp * sin(wt3 + shift_k)

% Generates a three phase sinusoidal reference signal
% with 120 degrees phase shift.
```

SRF-PLL



Control Systems/IGBT Control/SRF PLL/MATLAB Function

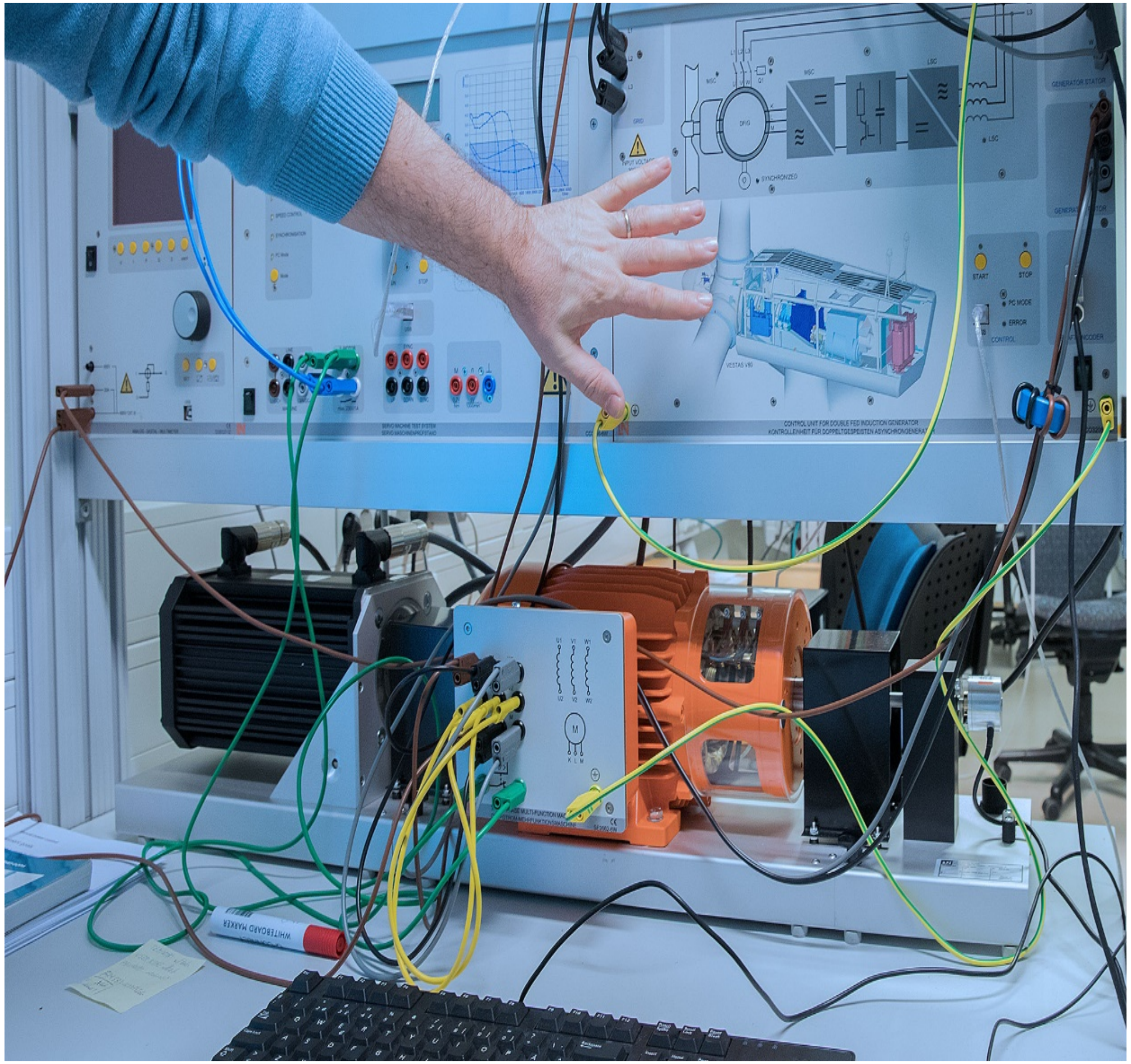
```matlab
function[a,b,c]=ref_generation(wt,amp,ph_shift)

shift_k=ph_shift*(pi/180);
a = amp * sin(wt + shift_k)
b = amp * sin(wt+shift_k-(2*pi/3))
c = amp * sin(wt+shift_k+(2*pi/3))

% Generates a three phase sinusoidal reference signal
% with 120 degrees phase shift.
```

Small wind power plant trainer

- Small wind power plants up to approx. 5 kW power are being deployed today for decentralized power supplies. These plants generate DC voltage. The energy can be stored in accumulator batteries using charge controllers. Inverters are used to generate AC voltage for operating consumers requiring the standard electricity supply voltage. The effects of wind power and the mechanical design of wind power stations can be emulated down to the last detail using the servo machine test stand and the software packages WindSim and MATLAB-Simulink. The corresponding Interactive Lab Assistant Multimedia course imparts knowledge, provides interactive experiment setup support and allows for PC-assisted evaluation of the measurement data.



Wind Power Plant Emulator

Intelligent Control of Energy Conversion and Storage Systems

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Faculty of Engineering

INTRODUCTION

This wind trainer (shown in next figure) is used to investigate the design and operation of modern wind power stations with double-fed induction generators. The effects of variable wind speeds and the mechanical/aero dynamical design of wind power stations can be emulated in realistic detail using the servo machine testing experimental stand and the *WindSim* software.

The control unit for the double-feed asynchronous machine (as a generator for the wind power plant) ensures user-friendly operation and visualization during the experiments. The corresponding Interactive Lab Assistant Multimedia course is designed to convey knowledge and provide interactive support for carrying out the experiments and allows for PC-assisted evaluation of the measured data.

The course approaches the student to the nature of the wind as a meteorological phenomena, and relates it to the structure of a wind power plant. The complete structure of a wind power plant is presented with a detailed description of the role of each component in the system.

Special emphasis is put in the functioning principle of a doubly-fed induction generator and its special mode of operation in relationship of the advantages it has for a wind power plant.

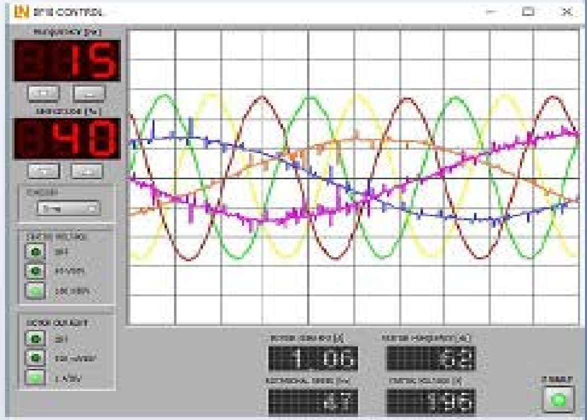
OBJECTIVES OF THE SETUP/WIND TURBINE TRAINER

- Understanding the design and operation of modern wind power plants
- Exploring the physical fundamentals "From wind to wave"
- Learning about different wind power concepts
- Setting up and commission a double-feed asynchronous wind generator
- Operating the generator with varying wind force levels and regulate the output voltage and frequency
- Manual and automatic synchronization with the 3-phase electricity grid
- Automatic control of active and apparent power, frequency and voltage
- Determining optimum operating points under changing wind conditions
- Investigating the operating response when there are faults on the grid ("fault ride-through")
- Understanding the role of the pitch control technique in a wind power plant

EXPERIMENTS

Influence of rotor speed on generator voltage

The goal of this experiment is to understand the relationship between a generator´s frequency and speed. The student will use the motor and the instrument *DFIG control*, by changing the mechanical speed it will be seen the variations on mechanical and voltage frequency.



Grid and stator voltage synchronization for a WT based DFIG

In this experiment, the user will use the *Synchronizer* instrument, and perform manually and automatically the synchronization of a DFIG on the electrical grid.

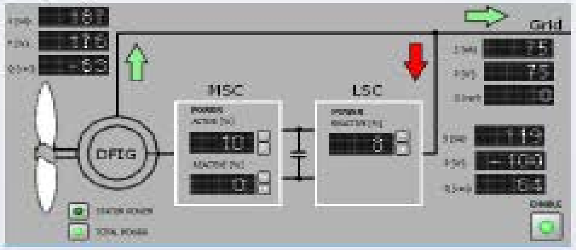
During this experiment, real (active) stator and rotor power is going to be injected into the grid, depending on the operation mode (sub synchronous or super synchronous speed).

EXPERIMENTS

Power control in a DFIG

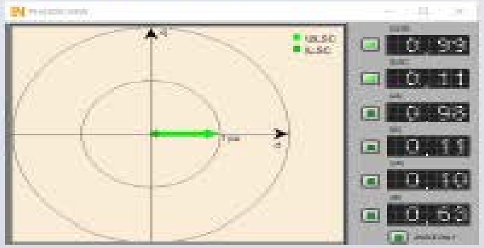
In this experiment, the *Power Control* instrument will be used to show stator and rotor power flow on a DFIG, the grid side converter will be controlled by the user in order to inject the required active power on the grid when the turbine is operating in three modes of operation:

- Synchronous
- Sub-synchronous
- Super-synchronous

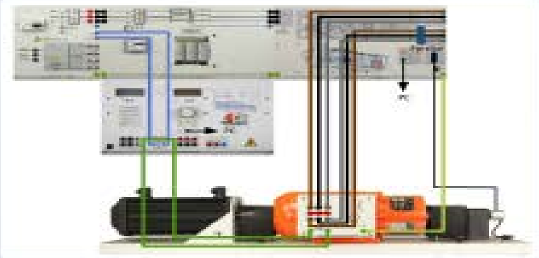


Reactive power control for the grid inverter

In this experiment, the grid side inverter will be controlled as a *STATCOM* to compensate the reactive power, and will visualize the phase shift between current and voltage and how to control it.



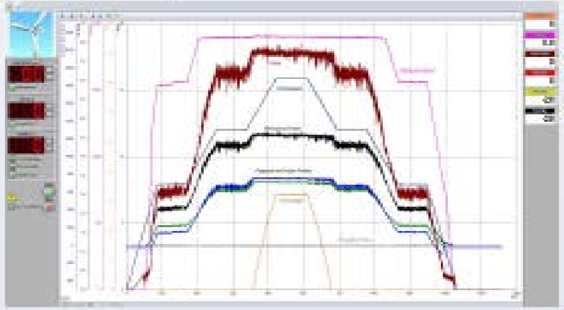
The virtual instrument used in this case will be the *Oscylloscope*.



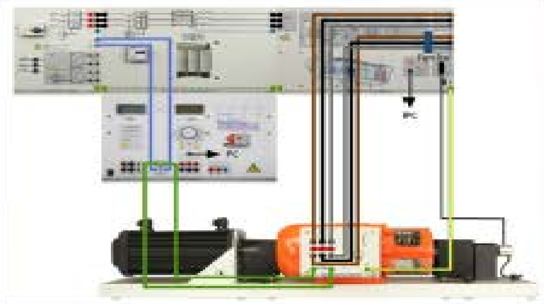
EXPERIMENTS

Wind profile experimental results

This profile is performed with the help of the *Control Center* virtual instrument. This virtual instrument allows to introduce an input of wind speed that can be programmed to last the desired time, by this, the different electrical and mechanical magnitudes present in the devices of the plant can be monitored and plotted.



The data can be exported as a picture, a bitmap or a txt file, allowing to be manipulated with powerful software such as MATLAB.



CONCLUSIONS

The accuracy of the devices and the measurement systems allows a realistic emulation of a wind power plant and its operation. The theoretical course successfully justifies the advantages of a DFIM as a generator in a wind plant by providing graphical explanations clearly to the student.

The experiments that the student has to perform are a precise tool for learning the operation of a wind turbine in different conditions: power output can be controlled along as grid synchronization.

By implementing wind profiles and monitoring the response of the different parts of the system the student learns the result of different scenarios and can perform experiments with a considerable degree of flexibility.

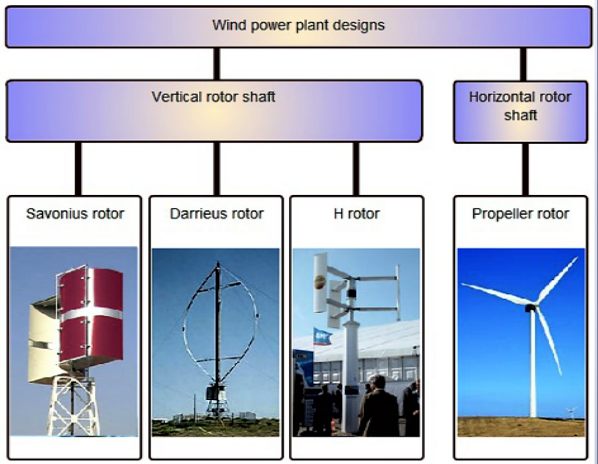
Wind Power Plants with DFIG

Intelligent Control of Energy Conversion and Storage System Lab

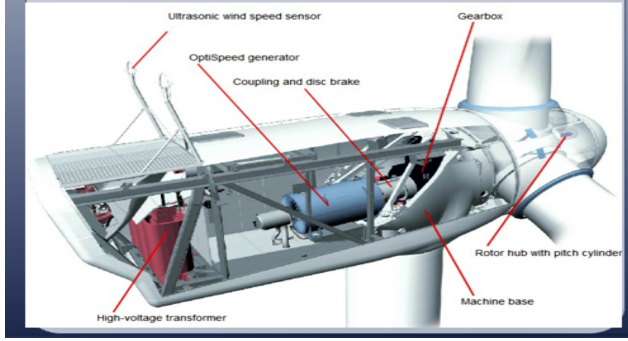
INTRODUCTION

A wind power plant converts the wind's kinetic energy initially into rotary motion. This is achieved by means of a rotor and connected shaft.

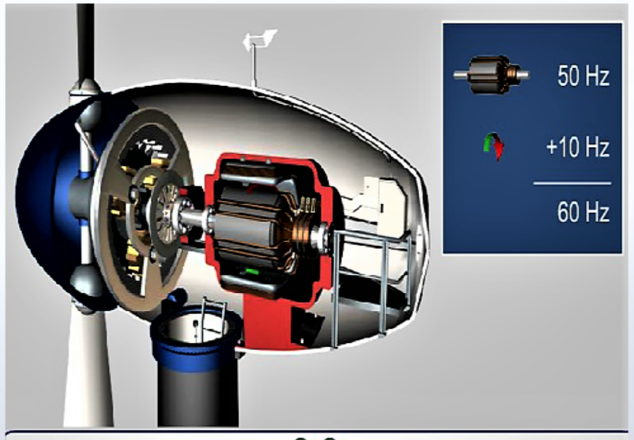
A wind power plant's rotor shaft can be mounted horizontally or vertically to result in the following variants:



Wind turbine components

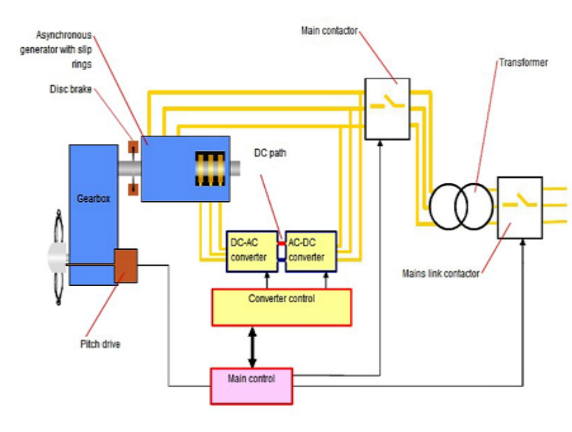


Doubly-fed Induction Generator



If the generator's rotor turns mechanically at a speed of 50 Hz (corresponding to 1500 rpm in the case of a 4-pole generator), the rotor's field must turn 10 Hz faster to produce a rotating field of 60 Hz in the stator.

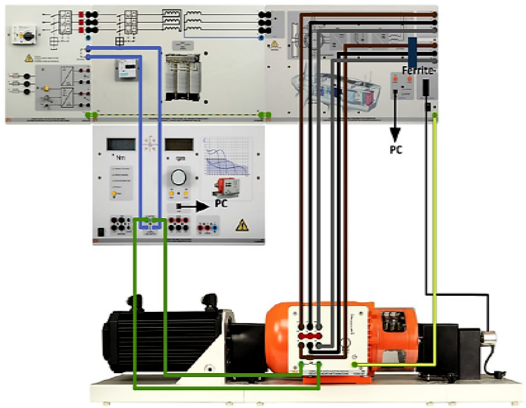
Speed control



In a doubly-fed generator, the rotor's speed can be varied by up to 30% of the rated speed. This raises power levels under changing wind conditions. It also minimizes undesirable fluctuations in the power grid and stresses exerted on the structure's crucial components.

Experimental setup and goals

Assemble the circuit according to the layout plan and wiring diagram



Equipment | Temperature / enable | PE-Connection | USB | Incremental encoder | Mains | Motor circuit | Complete wiring

Grid synchronization for a DFIG

Experiment goals

- Synchronizing the generator with the grid.
- Understanding the influence of rotor current and frequency.
- Synchronizing the generator automatically.

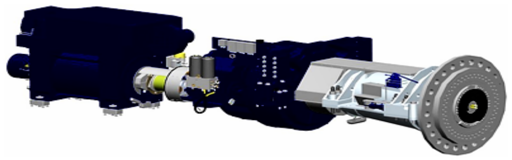
The following conditions must be met to connect the generator to the grid:

- Grid frequency = generator frequency
- Grid voltage = generator voltage
- Grid phase angle = generator phase angle

If a large-scale plant fails to meet any of these conditions, connecting the generator to the grid results in high compensation currents which can damage individual plant components. In the case of our experimental plant, connection can only take place within a window monitored by software. Connection commands issued outside the window are ignored.

Operation Modes of a DFIG

Operation of a doubly-fed induction generator



This chapter describes the function of a doubly-fed induction generator in wind power plants.

Key aspects are:

- Operating principle
- Voltage generation at different speeds
- Generator's synchronization with the grid
- Active power control
- Reactive power control

Active power control

Active power control

This chapter provides information on power control of a doubly-fed induction generator.

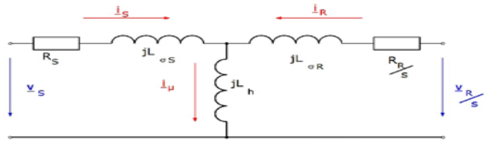
Key aspects are:

- Active power control
- Sub-synchronous operation
- Super-synchronous operation

In the previous chapter, the generator was synchronized with the grid but no power was transmitted.

Here we will learn how to control the generator so as to supply the grid with energy.

The relationships shown below can be derived from the generator's simplified equivalent circuit diagram.



Reactive power control

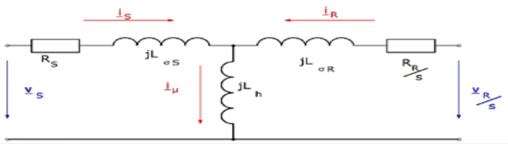
Reactive power control

This chapter describes control of a doubly-fed induction generator's reactive power.

Key aspects are:

- Overexcited operation
- Underexcited operation

Depending on the generator's excitation, reactive power can be drawn from the grid or fed into it. In this process, the generator can run mechanically in idle. Increasing the excitation via the MSC beyond the rated excitation causes the generator to supply the grid with reactive power. The generator then acts like a capacitor. Reducing the excitation to below the rated level causes the generator to draw part of its required reactive power from the grid. The generator then acts like a choke. In practice, network operators want overexcited operation to cover the grid's reactive power requirements. By contrast, wind energy producers would like to supply purely active power. The vector diagrams below represent operation with reactive power.



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Wind Turbine setup based DFIG

Intelligent Control of Energy Conversion and Storage System Lab

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OBJECTIVES OF THE SETUP/WIND TURBINE TRAINER:

Active and Reactive power control for the grid inverter

Influence of rotor speed on generator voltage

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Grid and stator voltage synchronization for a WT based DFIG

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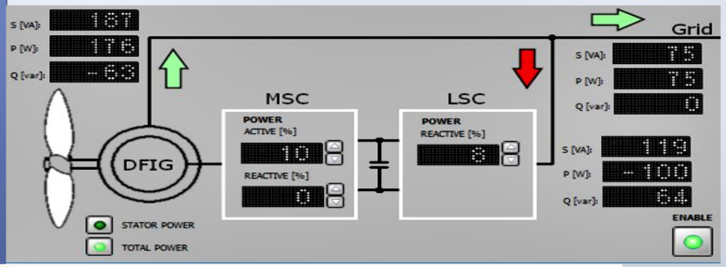
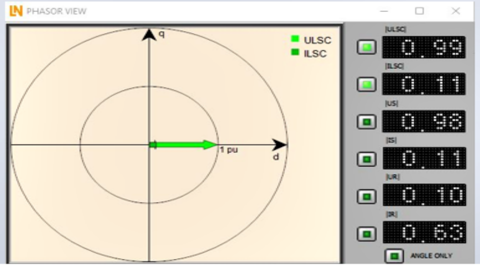
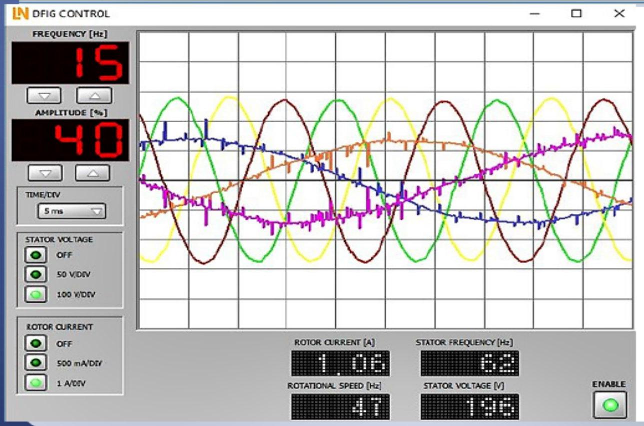
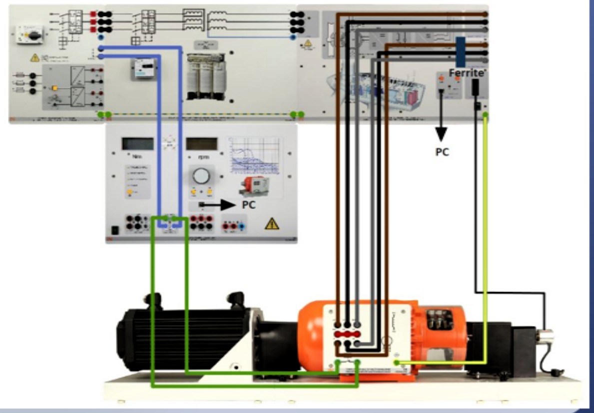
During this experiment, real (active) stator and rotor power is going to be injected into the grid, depending on the operation mode (sub synchronous or super synchronous speed).









Power Control instrument is used to show the stator and rotor power flow on a DFIG;

The grid side converter will be controlled by the user in order to inject the required active power on the grid when the turbine is operating in three modes of operation:

- Synchronous
- Sub-synchronous
- Super-synchronous

In this experiment, the grid side inverter will be controlled as a *STATCOM* to compensate the reactive power, and will visualize the phase shift between current and voltage and how to control it.

Special emphasis is put it in the functioning principle of a doubly-fed induction generator and its special mode of operation in relationship of the advantages it has for a wind power plant.

The virtual instrument used in this case will be generated by the software as a GUI.

Wind speed vs Wind Power

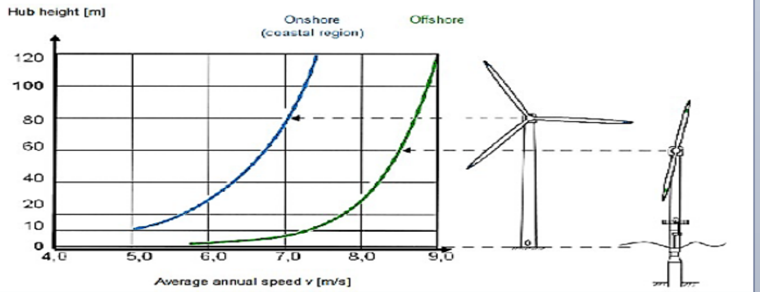
Intelligent Control of Energy Conversion and Storage System Lab

INTRODUCTION

A wind power plant converts the kinetic energy of air currents (wind) into electrical energy. Efficient operation is achieved at wind speeds which are neither too low nor too high. Operators of wind power plants seek locations which offer the best possible wind conditions for their plants.

Wind profile

The chart indicates that the average annual speed v_m is higher over sea than over land, despite the low hub height. This is because the surface of the sea is generally less rough compared with land, i.e. wind does not have to overcome as much friction at sea.



WIND POWER

The parameters involved in a transfer of power from wind to wind power plants are indicated below using a few typical installations as examples.

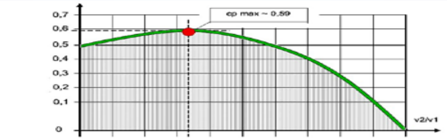
Power installation	Vestas V90 3MW	REPOWER M5	Nordex N100
Rated power:	3000 kW	5075 kW	2500 kW
Rotor diameter:	90 m	126 m	100 m
Swept rotor area:	6362 m²	12,469 m²	7854 m²
Speed range:	8.6 - 18.4 rpm	7.7 - 12.1 rpm	9.6 - 14.9 rpm
Circumferential travel of the blade tips:	283 m	395 m	314 m
Speed of the blade tips:	Approximately 86 m/s (312 km/h)	79 m/s (287 km/h)	Approximately 77 m/s (277 km/h)
Rated wind speed:	15 m/s	14 m/s	13 m/s
Shutdown wind speed:	25 m/s	25 m/s	20 m/s
Starting wind speed:	3.5 m/s	3.5 m/s	3 m/s
Wind power:	13.9 MW	22.2 MW	11.2 MW

The power of incident wind is calculated as follows:

$$P_{Wind} = \frac{1}{2} * \rho * A * v^3$$

ρ is the density of air (1.3 kg/m³), A the area covered by the rotor, and v the wind speed.

Wind turbine characteristic vs blade angle control



This maximum power coefficient $c_{p,max}$ is also termed the Betz limit. It is a theoretical, upper limit for the efficiency at which an ideal wind converter / rotor extracts wind power.

$$c_{p\,max} = \frac{16}{27} \approx 0{,}59$$

The power coefficient c_p is not a constant, but a function of the tip speed ratio λ and pitch angle β.

The tip speed ratio is defined as follows:

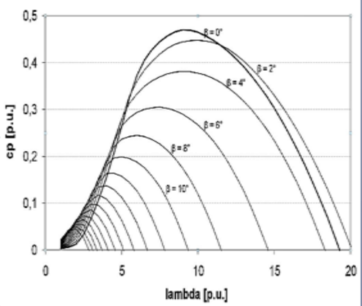
$$\lambda = \frac{\Omega * R}{v_1}$$

Ω: Speed

R: Rotor radius

v_1: Wind speed

The power coefficient is influenced, in particular, by the blades' geometric shape. The illustration below exemplifies c_p curves at different pitch angles.



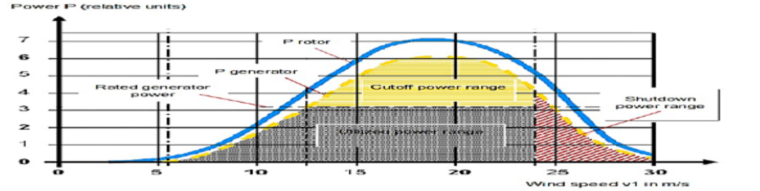
Operation of a wind power plant

This chapter describes the operation of a wind power plant.

Key aspects are:

- Wind power plant's operating ranges
- Operation at various wind intensities
- Power characteristic
- Pitch control
- Dynamic response to changes in wind condition

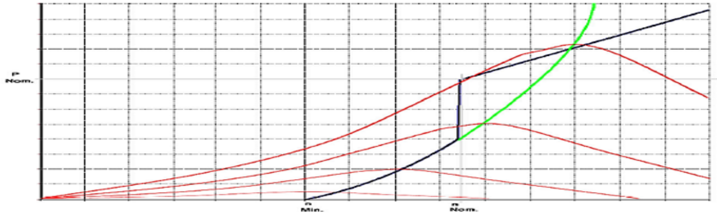
In accordance with wind speed, it is possible to differentiate between four different power ranges for a wind turbine.



Power characteristic of a DFIG

Power characteristic

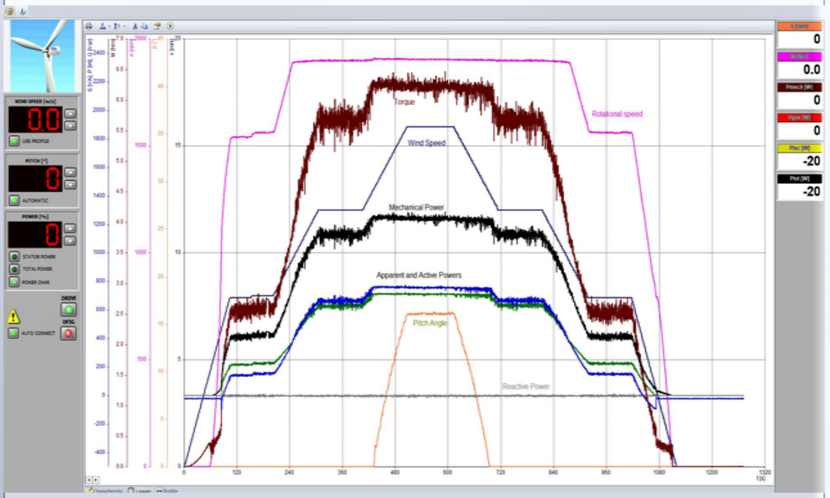
To maximize a wind power plant's output in the partial load range, i.e. below the generator's rated power, the plant must be operated as near as possible to the optimum tip speed ratio. For this, the rotor speed must proportionally track the wind speed, while the pitch angle is kept constant at 0°. However, wind speed cannot be measured accurately enough at such installations, the turbulence behind the rotor preventing measurements by means of a cup anemometer. Instead, the rotor's theoretical performance map is used to derive a control characteristic which passes through the aerodynamic power maxima at the various wind speeds. This results in a speed-dependent power control characteristic. Illustrated below is the control characteristic (blue) as well as the wind's power characteristics (red). The green branch of the control characteristic represents the theoretical curve.



In the full load range, the wind turbine's output must be limited to the generator's nominal power. In the case of variable-speed plants, this can be achieved by a constant setpoint power or torque (in our case, it is the torque). The aerodynamic power is limited indirectly by a speed controller which uses the pitch angle as the manipulated variable. In other words, the wind turbine's speed in the full load range is kept constant via the pitch angle.

In the case of real wind turbines, the selected nominal speed is usually lower than the corresponding value on the optimal aerodynamic power characteristic. As a result, the control characteristic rises more steeply in the upper range, and the wind turbine's power output is no longer maximized.

Experimental results: Wind power profiles vs wind speed



Wind turbine setup description

The wind turbine setup's goal is to emulate a wind power plant connected to the grid and using a *Vestas V90* wind turbine for power generation. Figure 4.2 shows the components of the setup:

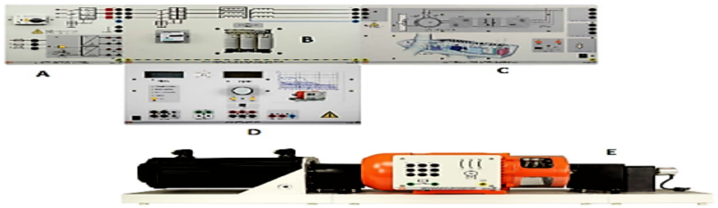


Figure 4.2: DFIG wind turbine setup

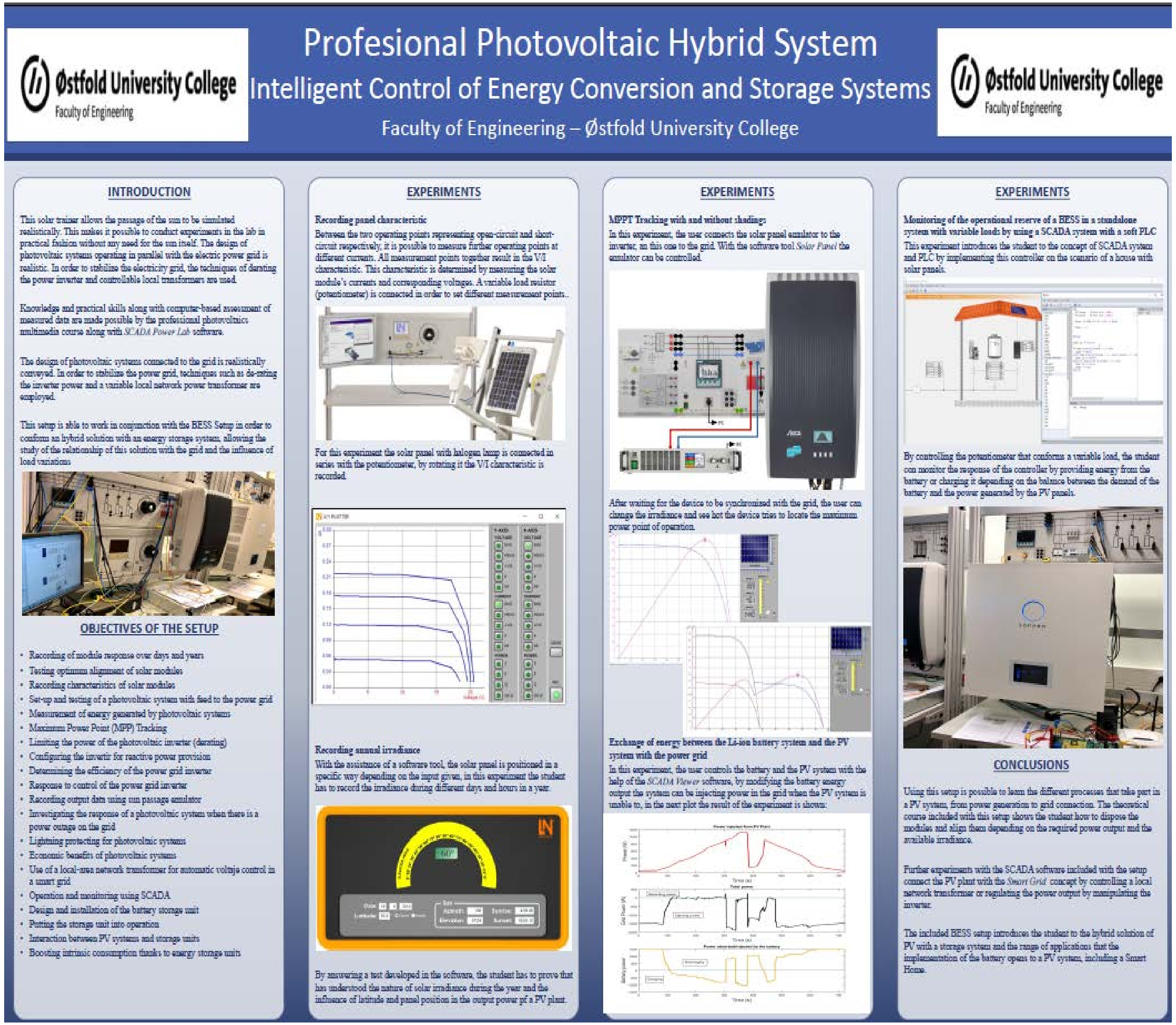
- **A. Power supply for electric machine:** This power supply unit is especially designed for operation with electrical machines, it takes power from the grid in order to inject on the grid the power generated by the DFIG machine. This devices supplies with three phase 230V_{LL} AC voltage at 50 Hz since this setup is made for the European Grid.
- **B. Three-phase isolating transformer for a wind power plant:** This device is a transformer very common in wind plants for grounding protection in case of faults, it will be placed between the power supply and the DFIG.
- **C. Controller for a wind power plant's doubly-fed induction generator:** This device is connected to the PC and is controlled with virtual instruments, it controls the rotor of the DFIG via virtual instruments on the PC, an encoder is connected from the DFIG to perform that control.

4.1. DFIG WIND TURBINE SETUP

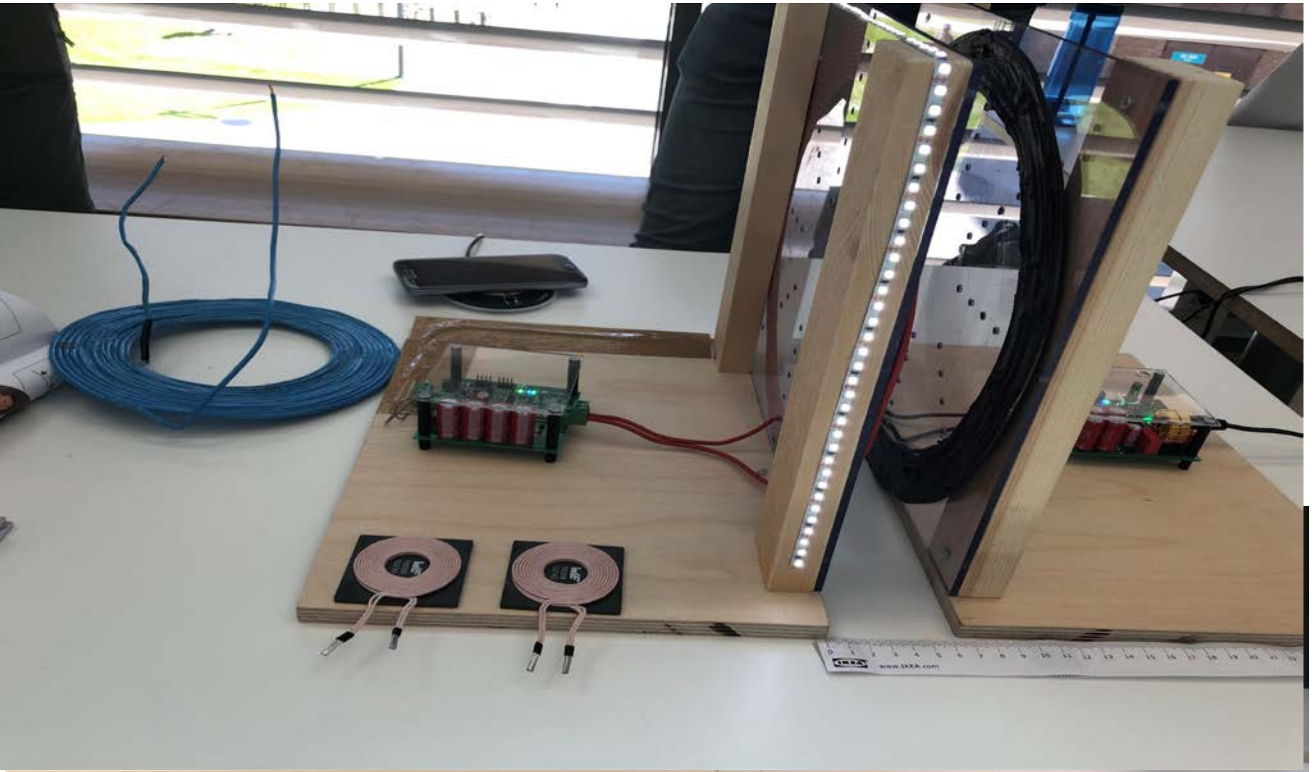
- **D. Servo-machine test stand (1 kW):** This servo machine is connected with the DFIG and will emulate the mechanical part of the wind turbine, a panel controlled via virtual instruments will manage the servo in order to recreate wind,
- **E. Three-phase, multi-function machine (doubly fed generator) (0.8 kW):** This machine emulates the generator of the wind turbine. An encoder is connected as interface between this machine and the controller. This generator will share the same shaft with the servo machine.

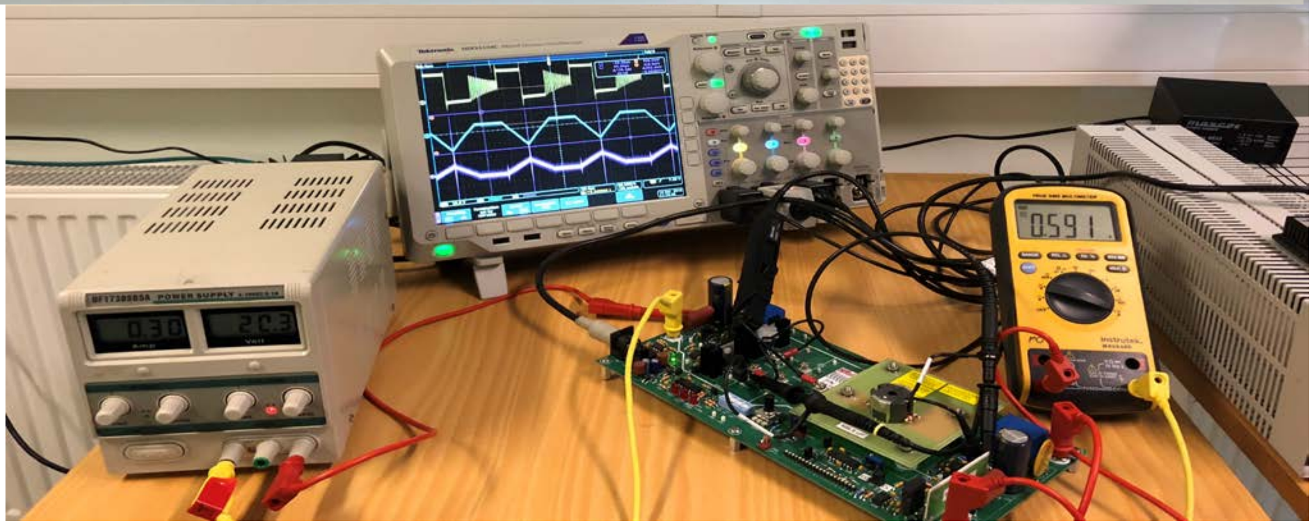
Battery Storage System as hybrid solution in Smart Buildings

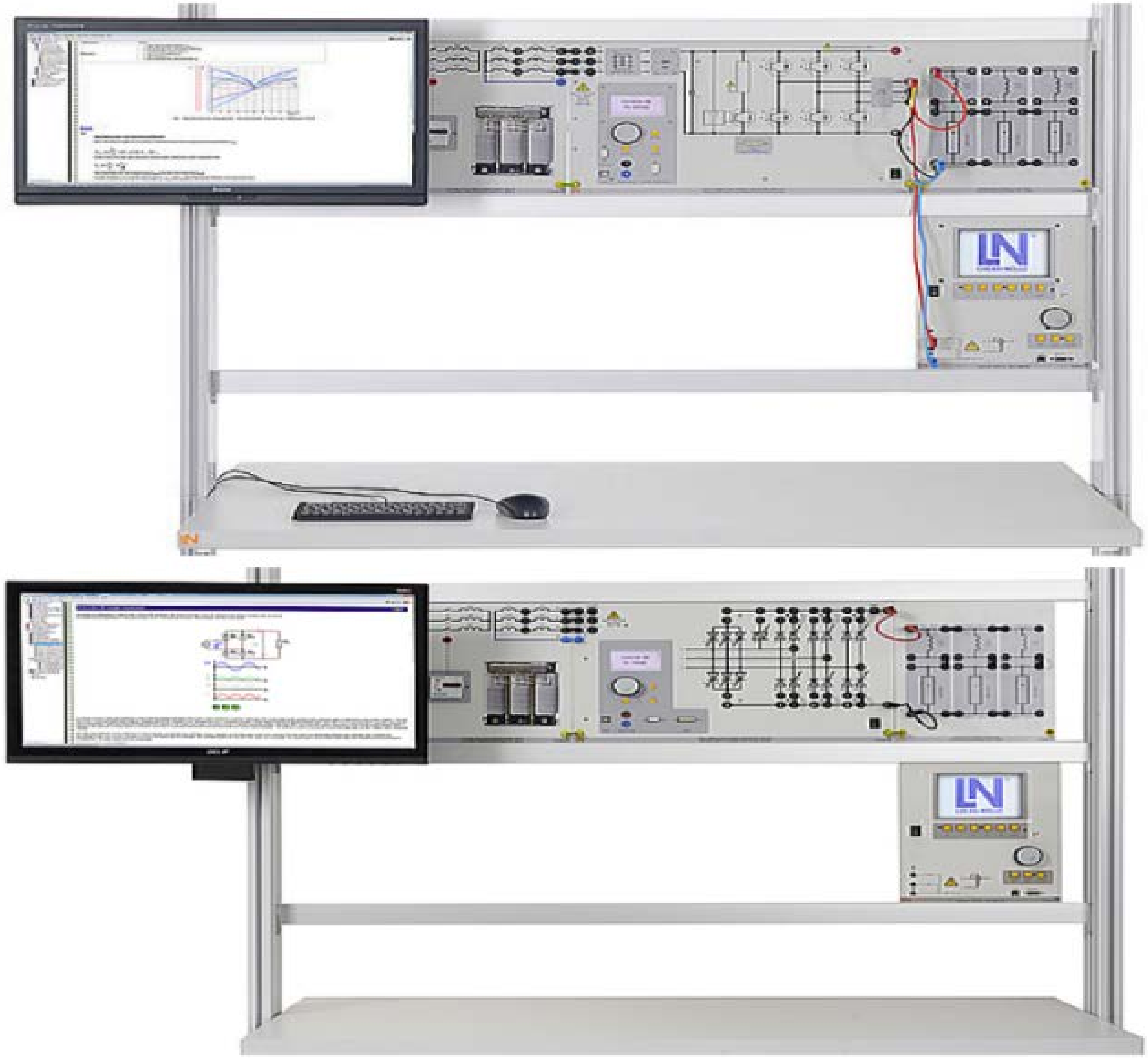
- Training contents:
- -Design and installation of the battery storage unit
- -Putting the storage unit into operation
- -Remote control of energy storage units using SCADA software
- -Optimizing operating response through smart consumers (loads)
- -Storage unit integration into a smart grid
- -Investigation of battery storage units in conjunction with Photovoltaic (PV) systems, Wind Power Plants;



Power electronics converters topologies. AC/DC, DC/AC and DC-DC converters







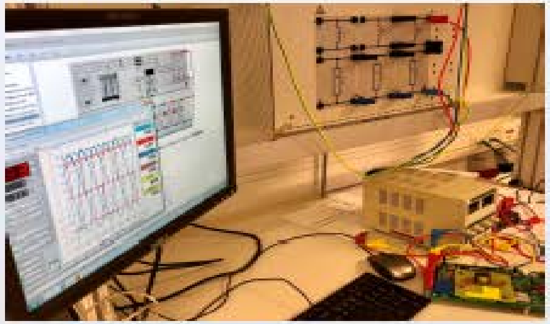
Line-commutated power electronic converters

Intelligent Control of Energy Conversion and Storage Systems

Faculty of Engineering – Østfold University College

INTRODUCTION

This setup seeks to provide the student with knowledge of the various circuits used for line-commutated converters. In addition to building these circuits, the student will also investigate how the circuits respond in the course of various experiments.



The training system for line-commutated converter circuits enables assembly and study of power electronics circuits with IGBTs. In addition to power semiconductors, the system caters for control and measurement of all relevant parameters. Virtual instruments are available for the operation and recording of measurements. Alternatively the system can also be operated without a PC. An interactive multimedia course serves as the instruction manual.

OBJECTIVES OF THE SETUP

- Familiarization with most common line-commutated converter circuits
- Analysis of how voltage and current change over time in the various circuits
- Analysis of a how a free-wheeling circuit affects the response
- Hole storage effect (accumulation of minority charge carriers in semiconductors)
- Control characteristics of line-commutated converters

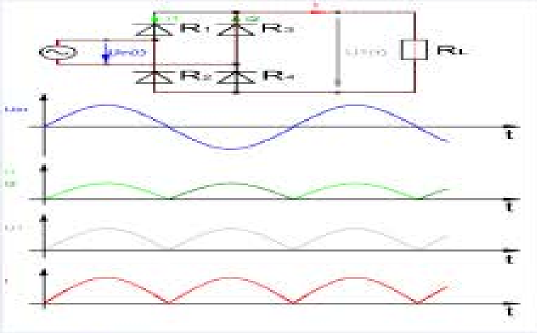
The circuits covered in this setup are the following:

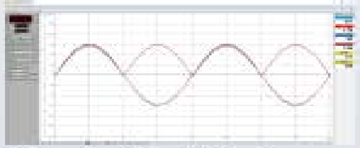
- Single-pulse mid-point (center-tapped) rectifiers (M1) - controlled and uncontrolled
- Two-pulse bridge rectifiers (B2) - controlled, half-controlled and uncontrolled
- Six-pulse bridge rectifiers (B6) - controlled and uncontrolled
- Single-phase AC power controllers (W1)
- Three-phase AC power controllers (W3)

EXPERIMENTS

Single phase diode rectifier with resistive load

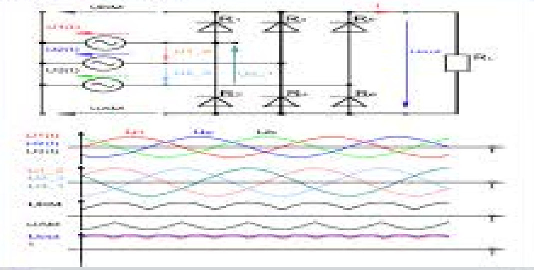
In this experiment, the student connects the setup to conform a single phase diode rectifier, and the load as purely resistive, with the help of the *Converter Control* virtual instrument.

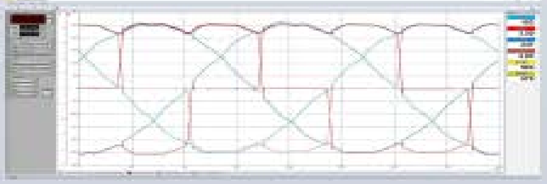




Three-phase diode rectifier with resistive load

The setup is now modified to conform a three-phase diode rectifier, the waveform that the student will see on the *Converter Control* virtual instrument is the following:

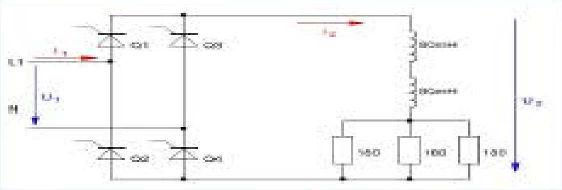




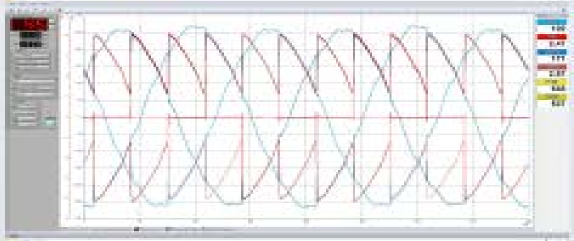
EXPERIMENTS

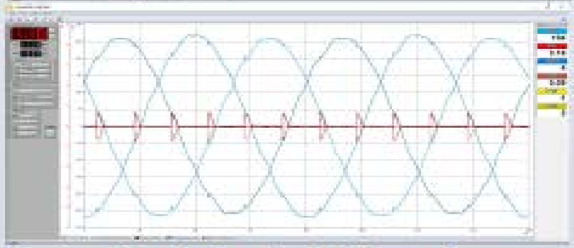
Three-phase thyristor rectifier

This experiment can be performed with the appropriate panel, the load panel wiring can be modified in order to show the waveforms with resistive or inductive load.

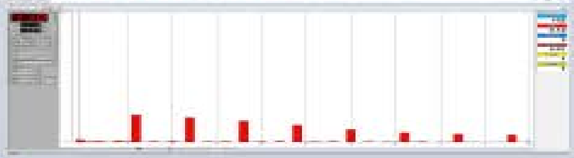


The student can control the firing angle and display the waveforms in inverter and rectifier mode.



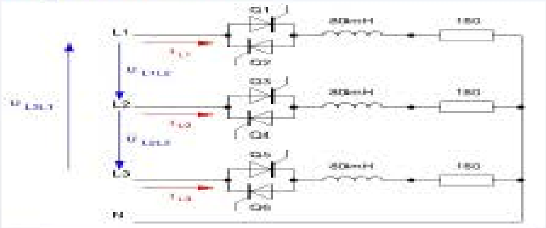


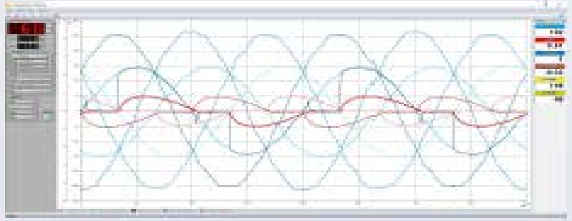
Harmonic analysis can be also performed with voltages and currents



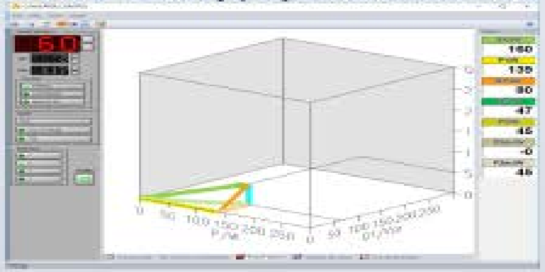
EXPERIMENTS

Three-phase TRIAC converter





The virtual instrument can display the power vectors in three dimensions



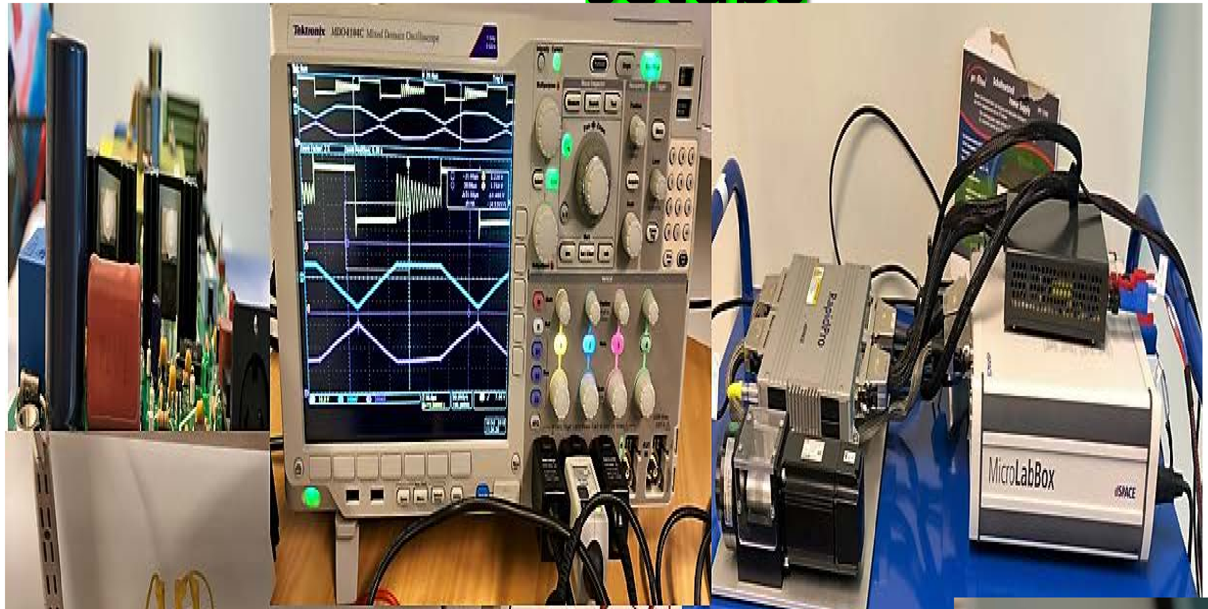
CONCLUSIONS

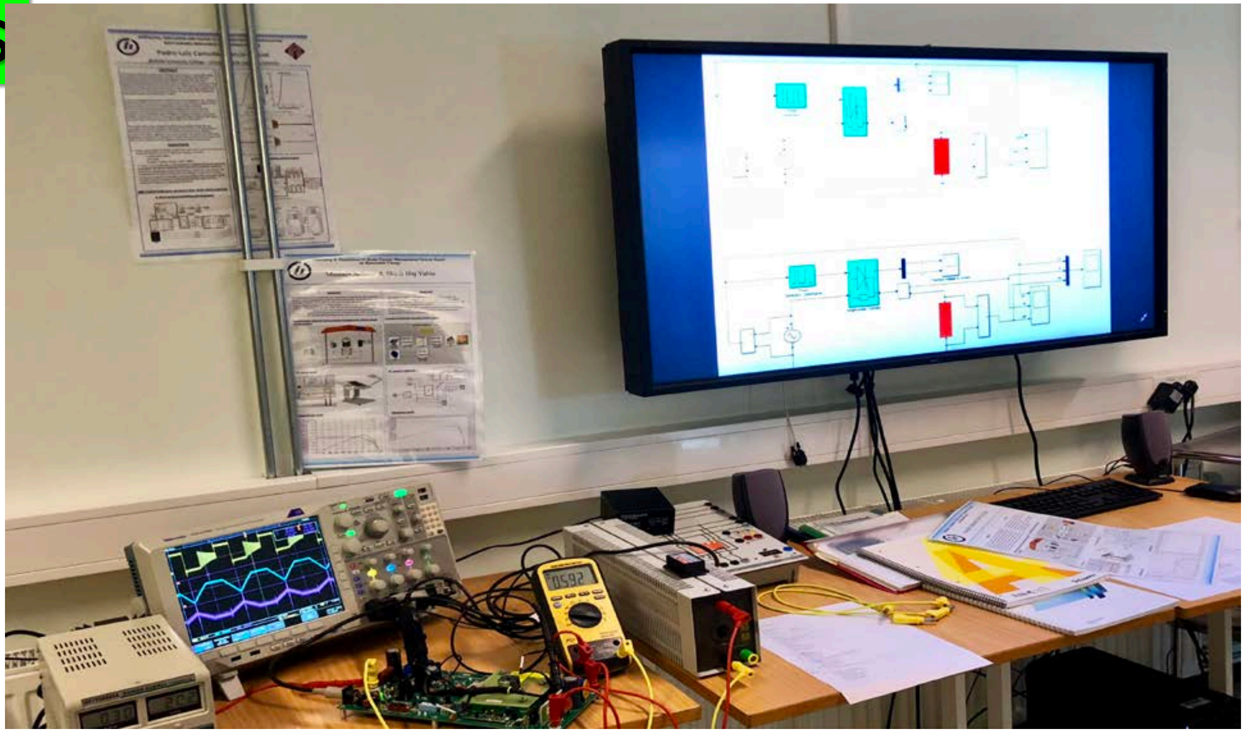
Using this setup we can study and analyze all types of line frequency converters with single semi-conductor, single-phase full-bridge and three-phase configurations.

We can monitor and analyze the input and output parameters of this converters using harmonic analysis FFT by displaying current and voltage spectrum but also phasor diagrams displaying the power vectors using a virtual instrument.

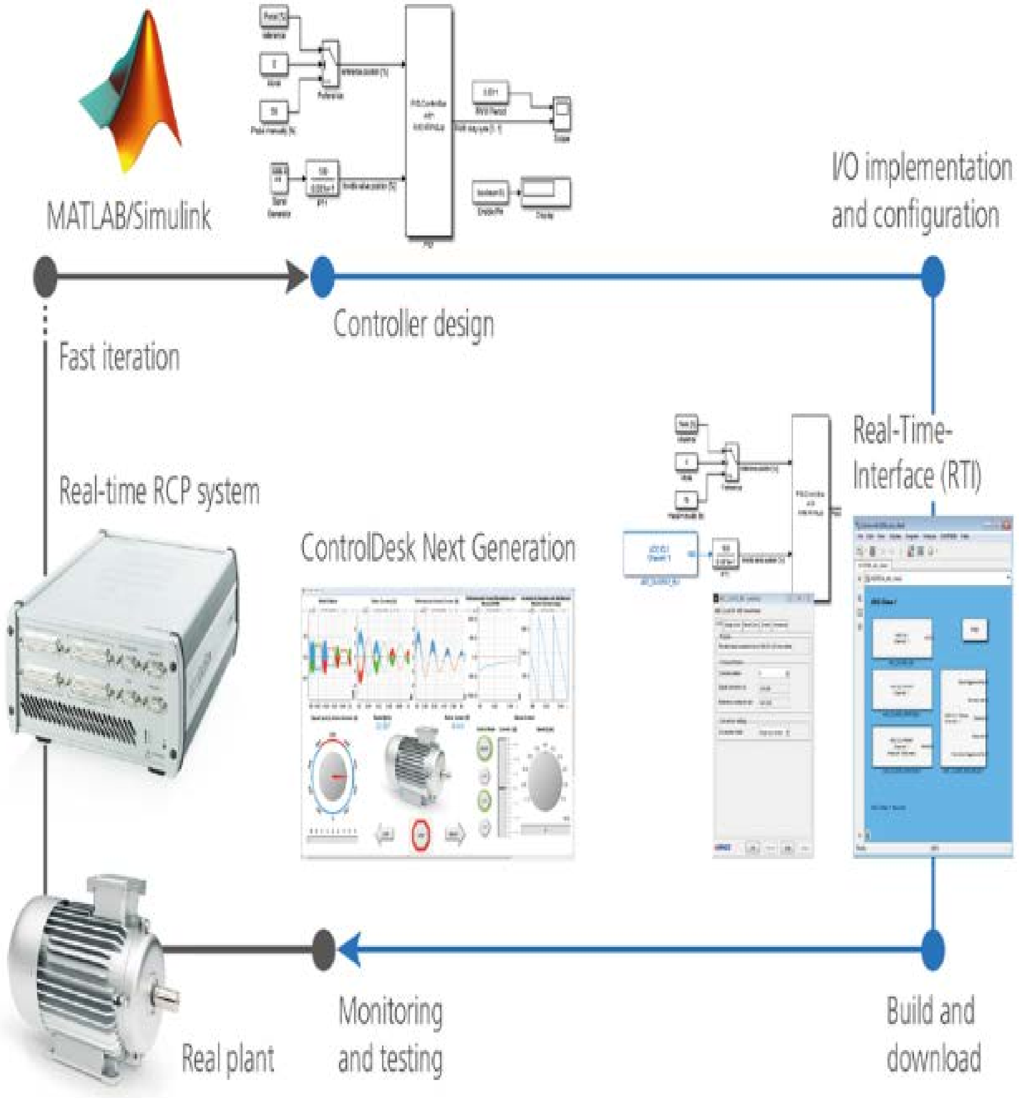
The data can be saved as a picture, as a bitmap or a text file giving the possibility to be manipulated with a powerful software such as MATLAB Simulink.

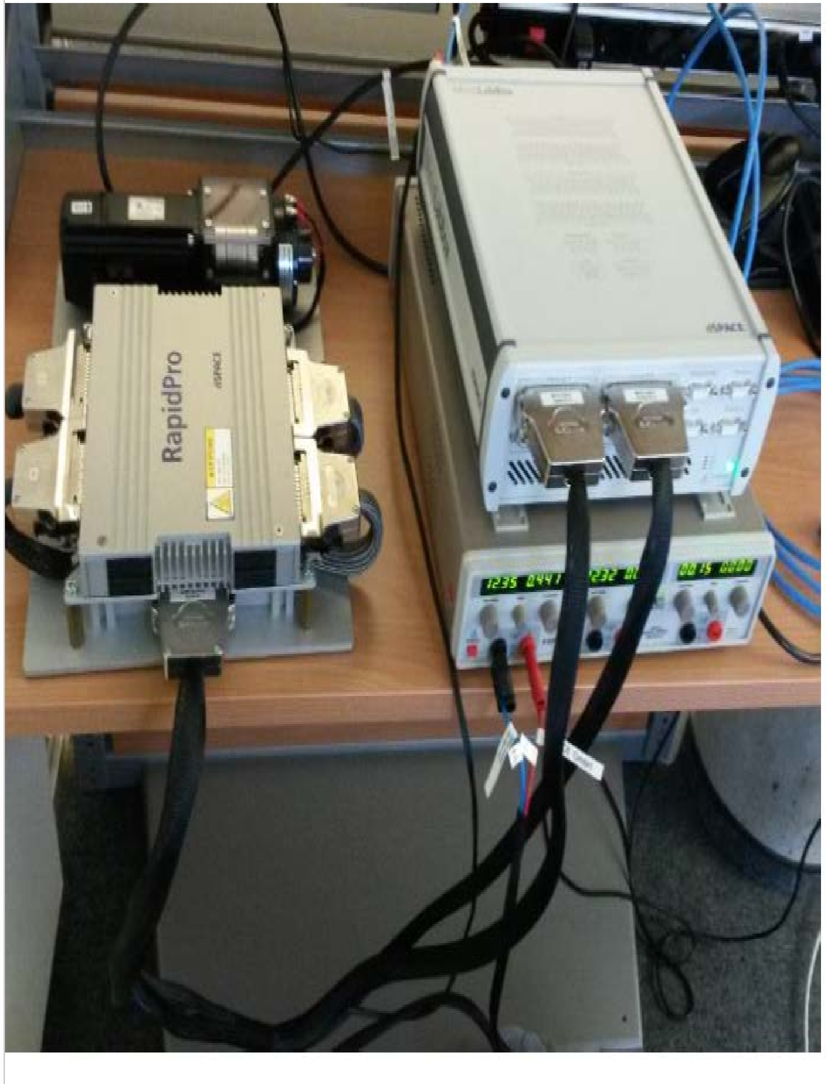
Power electronics and electric drives setups



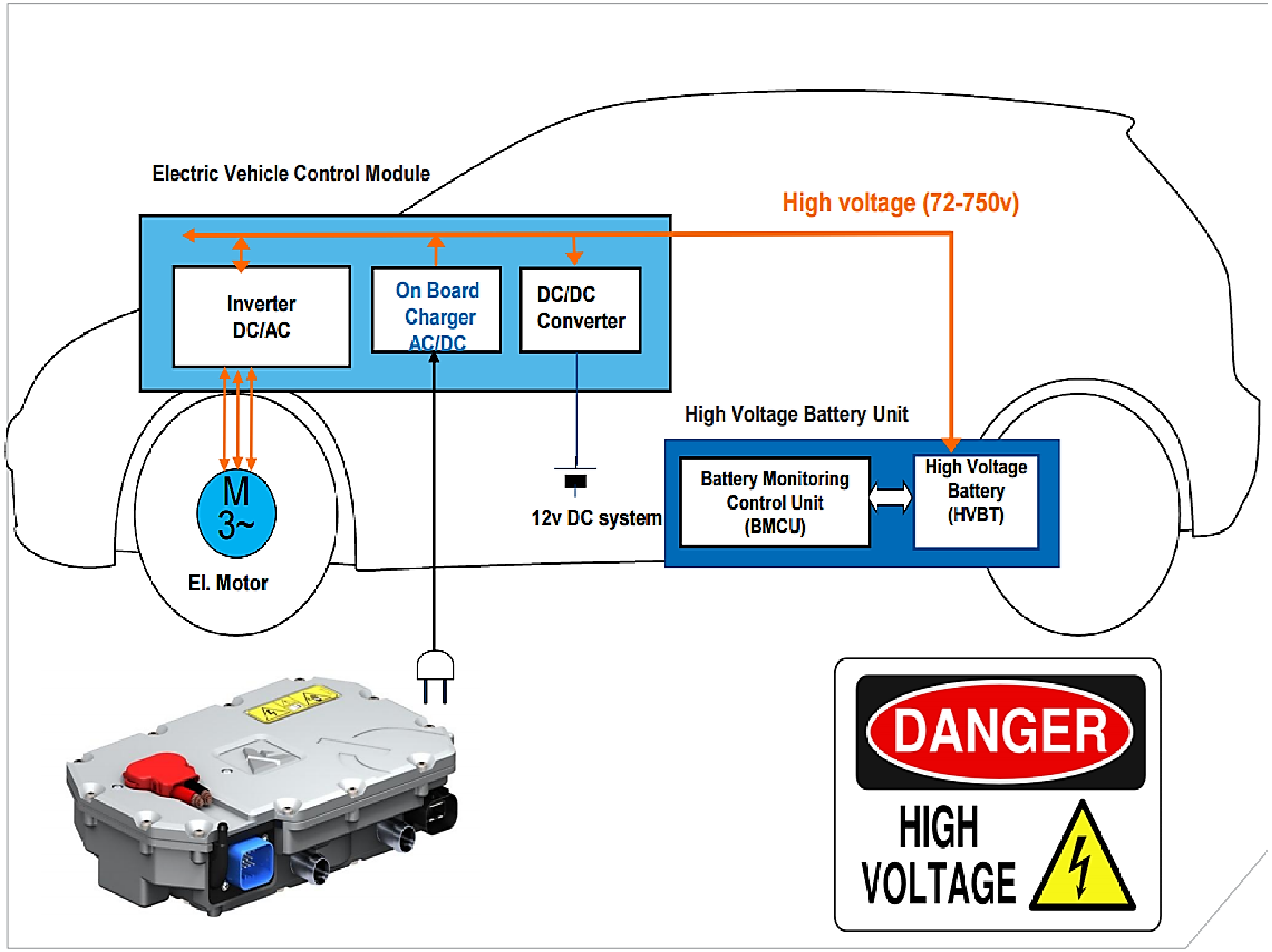


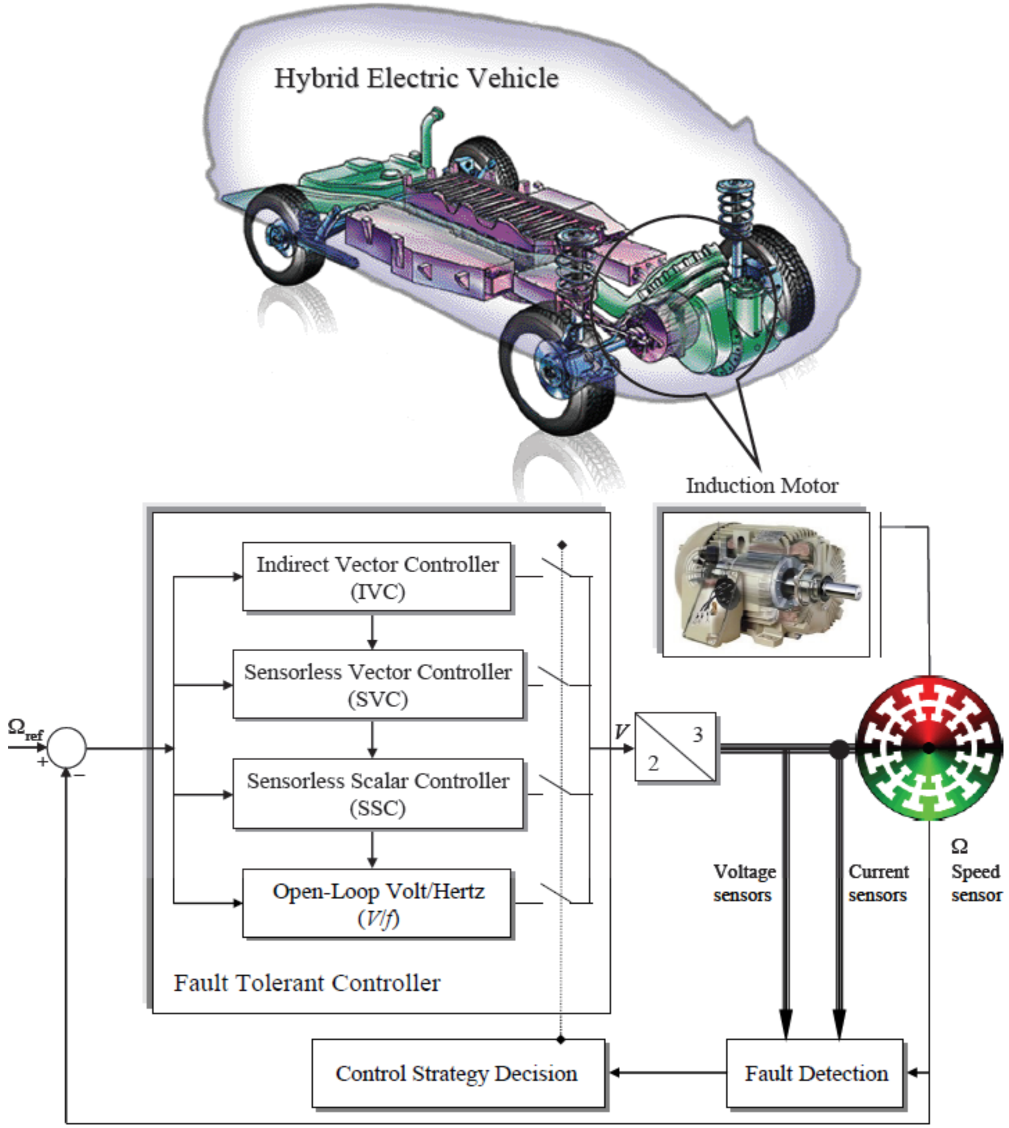
Electric drives with DC and AC motors. Real-time digital simulation and designing drive controllers using MATLAB-Simulink.



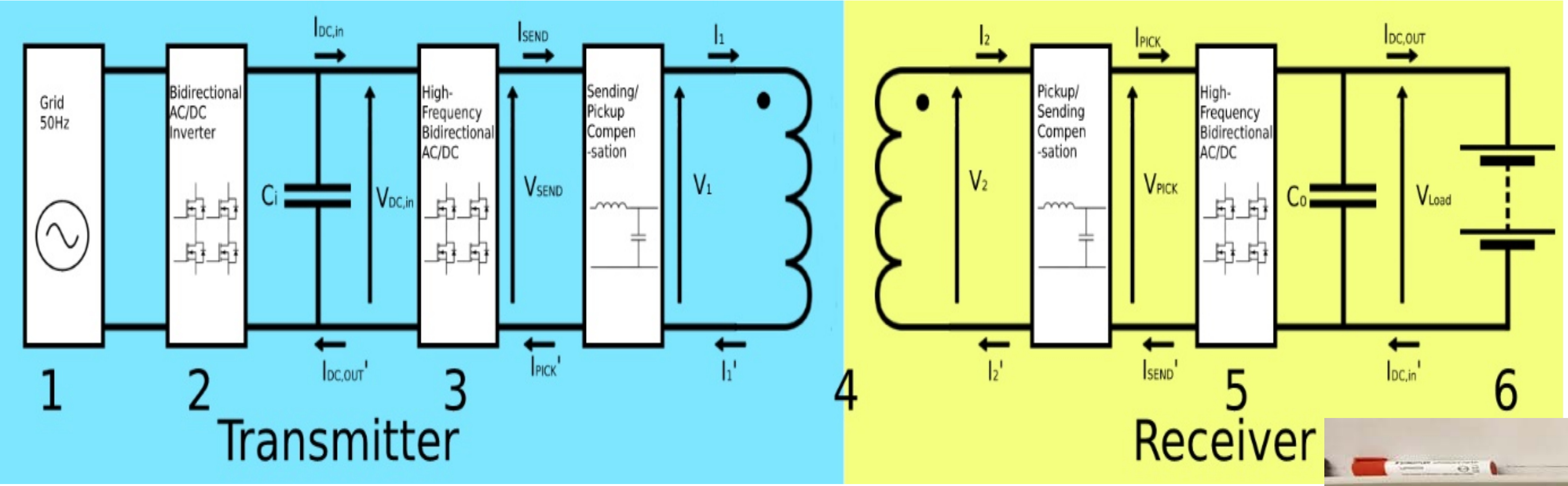


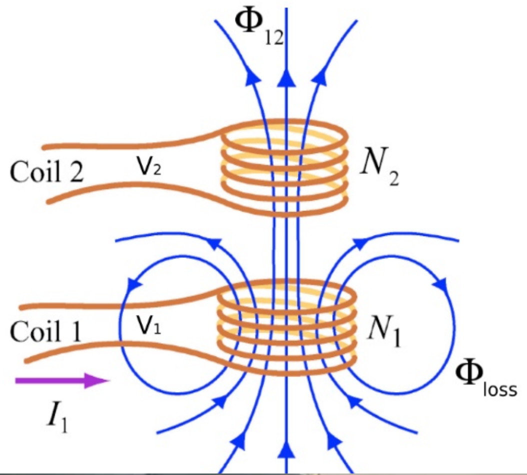
Full Electric and Hybrid Vehicles

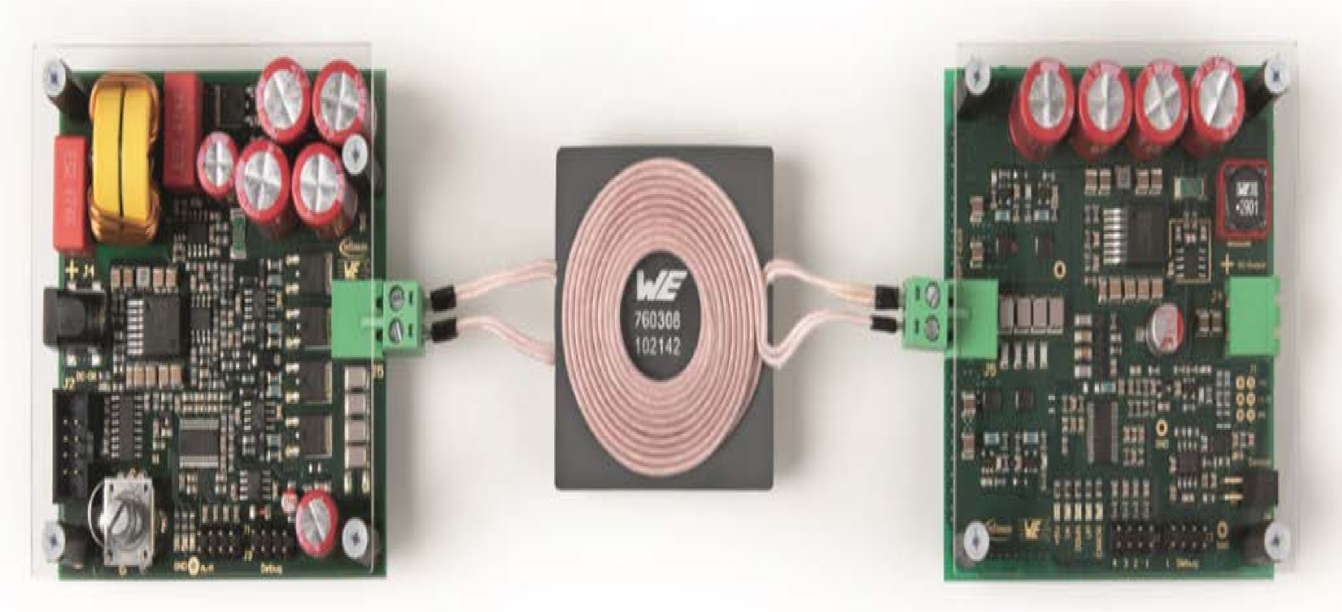


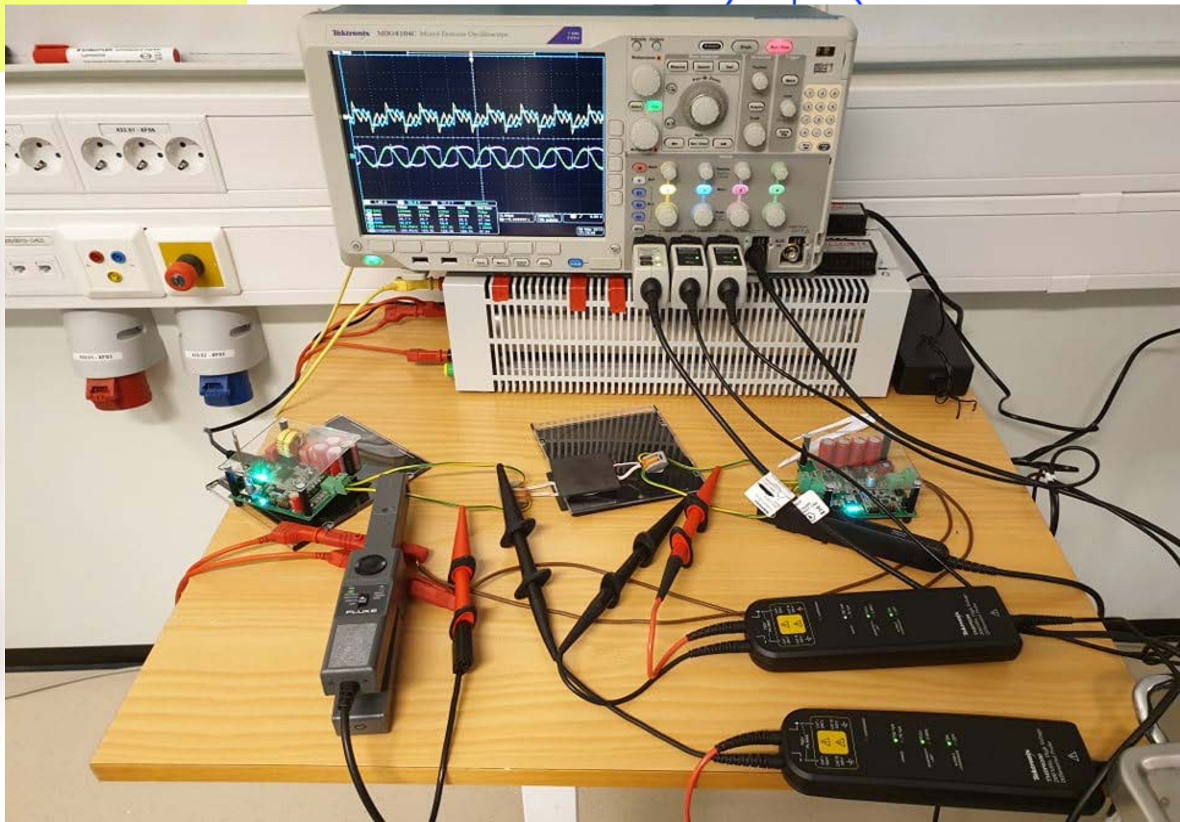


Wireless charging systems









Lab facilities-DER components in a Smart Grid