Warsaw University of Technology
Faculty of Electrical Engineering

Institute of Control & Industrial Electronics

current projects and activities
A survey

Marek Jasiński

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Zielona Góra, Polska, the 20-th of September 2013

Warsaw University of Technology, Faculty of Electrical Engineering
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SEMINARIUM

ENERGOELEKTRONIKA W ROZPROSZONEJ ENERGETYCE I POJAZDACH ELEKTRYCZNYCH

20 września 2013 r., Uniwersytet Zielonogórski

Warsaw University of Technology, Faculty of Electrical Engineering
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- Wprowadzenie

- Przegląd projektów

- Wybrane zagadnienia w sterowaniu sprzęgów energoelektronicznych AC-DC-AC pomiędzy odnawialnymi źródłami energii a siecią elektroenergetyczną

Warsaw University of Technology

The origins of Warsaw University of Technology (WUT) date back to 1826 when engineering education was begun in Warsaw Institute of Technology.

Warsaw University of Technology is the largest academic school of technology in Poland, employing 2.000 professors. The number of students is 30.000, most of them study full-time. There are 17 faculties covering almost all fields of science and technology. All of them are situated in Warsaw except for one in the city Płock.

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Faculty of Electrical Engineering

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- **Faculty of Architecture**
- **Faculty of Automobiles and Heavy Machinery Engineering**
- **Faculty of Chemical and Process Engineering**
- **Faculty of Chemistry**
- **Faculty of Civil Engineering**
- **Faculty of Electrical Engineering**
- **Faculty of Electronics and Information Technology**
- **Faculty of Environmental Engineering**
- **Faculty of Geodesy and Cartography**
- **Faculty of Materials Science and Engineering**
- **Faculty of Mathematics and Information Science**
- **Faculty of Mechatronics**
- **Faculty of Physics**
- **Faculty of Power and Aeronautical Engineering**
- **Faculty of Production Engineering**
- **Faculty of Transport**

Faculty of Electrical Engineering

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GENERAL INFORMATION

The Faculty of Electrical Engineering was established in 1921.

It is located in the Electrical Engineering Building, in the Mechanics Building and partly in 3 other buildings which are situated on the University's Central Campus.

Student enrolment to the Faculty is approximately 400 annually and the total number of students is about 2000, including extra-mural students.

The Faculty employs an academic staff of 167, including 23 professors, 10 associate professors and 134 assistant professors. These are supported by 110 technical and administrative staff.

http://www.ee.pw.edu.pl

Faculty of Electrical Engineering

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ORGANISATION

The Faculty is divided into five institutes:

- The Institute of Electrical Power Engineering,
- The Institute of the Theory of Electrical Engineering and Electrical Measurements,
- The Institute of Control and Industrial Electronics – (ICIE),
- The Institute of Power Engineering and High Voltage Technology,
- The Institute of Electrical Machines.
- The Faculty has two institute libraries.

Warsaw University of Technology, Faculty of Electrical Engineering
Institute of Control & Industrial Electronics
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The history of the *Institute of Control and Industrial Electronics* goes back to 1968 when in the Electrical Engineering Faculty the Chair of Fundamentals of Electronics and Control was established.

In 1970 the Electrical Engineering Faculty was reorganized and five Institutes settled down there.
One of them the Institute of Automatic Control and Industrial Electronics consisted of three divisions:

- **Control Division** – research on: control theory, image processing, system approximation and real-time system control.

- **Industrial Electronics Division** – research on: components and converters, control and signal processing in power electronics, power equipment.

- **Electrical Drives Division** – research on: electrical drives and its control, converters for drive applications, non-conventional systems of power generation and power conditioning.

Institute of Control and Industrial Electronics
ICIE

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Warsaw University of Technology
Department of Electrical Engineering
Institute of Control and Industrial Electronics
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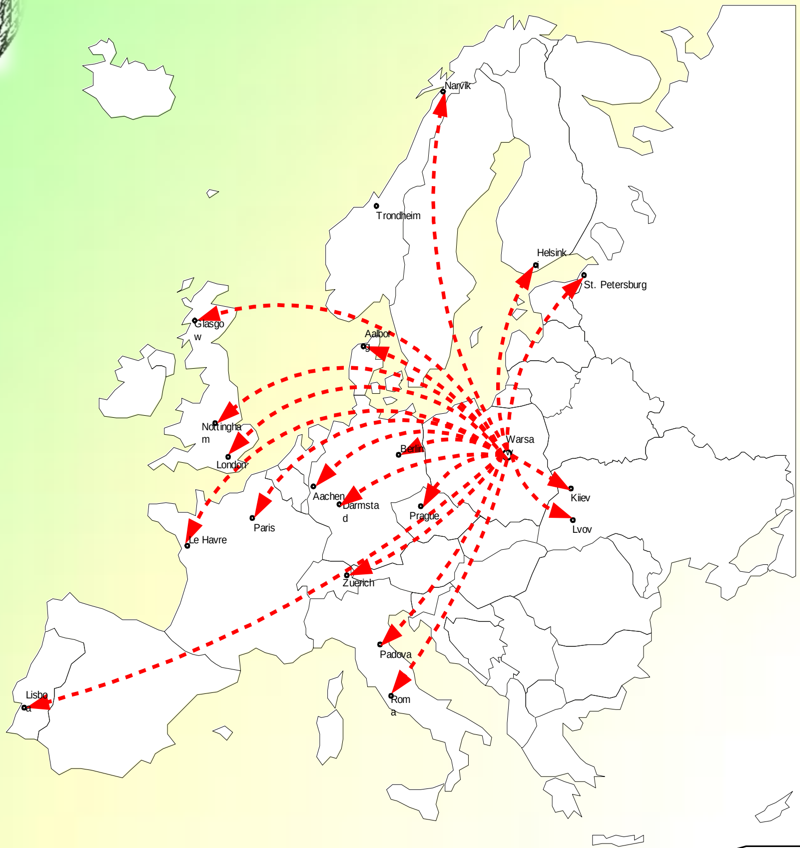
Deputy Director for Science and Research – Bartłomiej Ufnalski, Ph.D.
Deputy Director for Education - Paweł Fabijanski, Ph.D.

Control Division
Head – Bartłomiej Beliczynski
Prof., Dr.Sc., Ph.D.

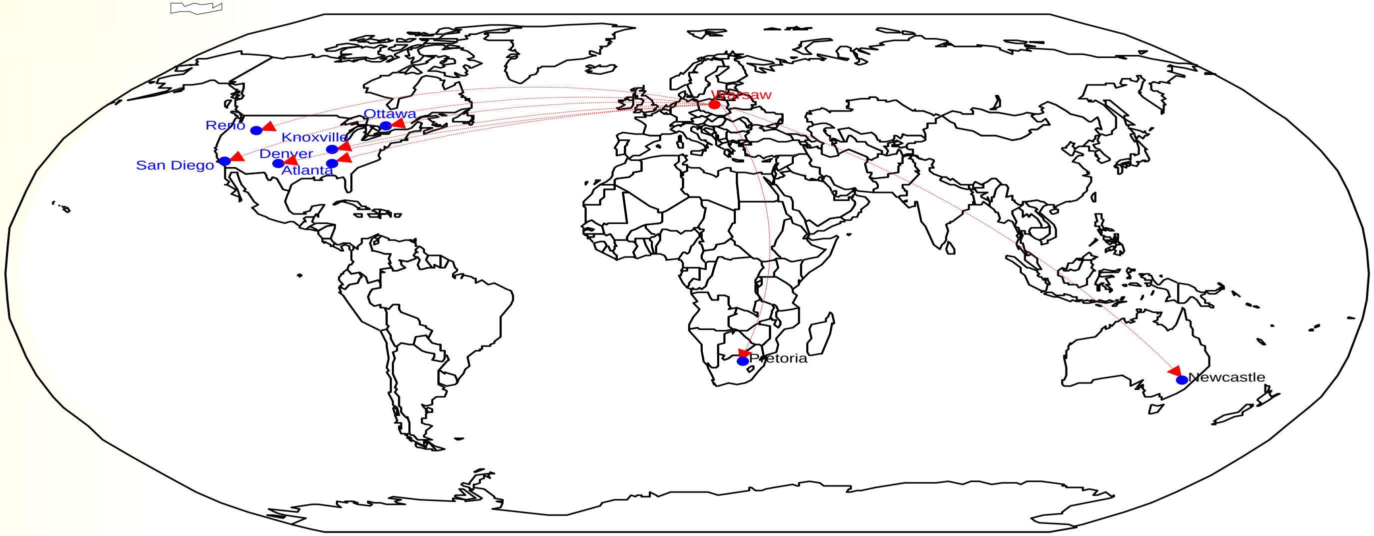
Industrial Electronics Division
Head – Roman Barlik
Prof. Dr.Sc., Ph.D.

Electrical Drive Division
Head - Włodzimierz Koczara
Prof. Dr.Sc., Ph.D.

International partners of ICIE



- Aalborg University (Denmark),
- University of Nevada (USA),
- Technische Universitat Berlin TU (Germany),
- University of Cergy-Pontoise (France),
- University of Federico Santa Maria (Chile),
- ENSEEIHT - Laplace (France),
- ETH Zurich (Switzerland),
- Alcala University (Spain),
- Technical University of Catalonia (Spain),
- University of Seville (Spain),
- Indian Institute of Science, Bangalore (India),
- IKERLAN, Mondragón (Spain),
- Texas AM (Qatar),
- Technical University of Lisbon (Portugal)
- RWTH Aachen University (Germany)
- etc



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Industrial cooperation of ICIE

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MEDCOM
AC & DC POWER SOLUTIONS
TRACTION CONVERTERS

TWERD

HÜTTINGER Elektronik

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Intelligent Control Group - ICG

Prof Marian P. Kaźmierkowski

PhD Dariusz Sobczuk

PhD Mariusz Malinowski

PhD Marek Jasiński

MSc Małgorzata Bobrowska-Rafał

MSc Szymon Piasecki

MSc Michał Rolak

MSc Grzegorz Wrona

MSc Sebastian Styński

MSc Marcin Sędłak

MSc Krzysztof Rafał

MSc Paweł Młodzikowski

MSc Radosław Kot

MSc Adam Milczarek

MSc Kamil Antoniewicz

MSc students

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„Sensorless inverter drive with Direct Torque Control SVM for 160kW induction motors based on new signal processor”

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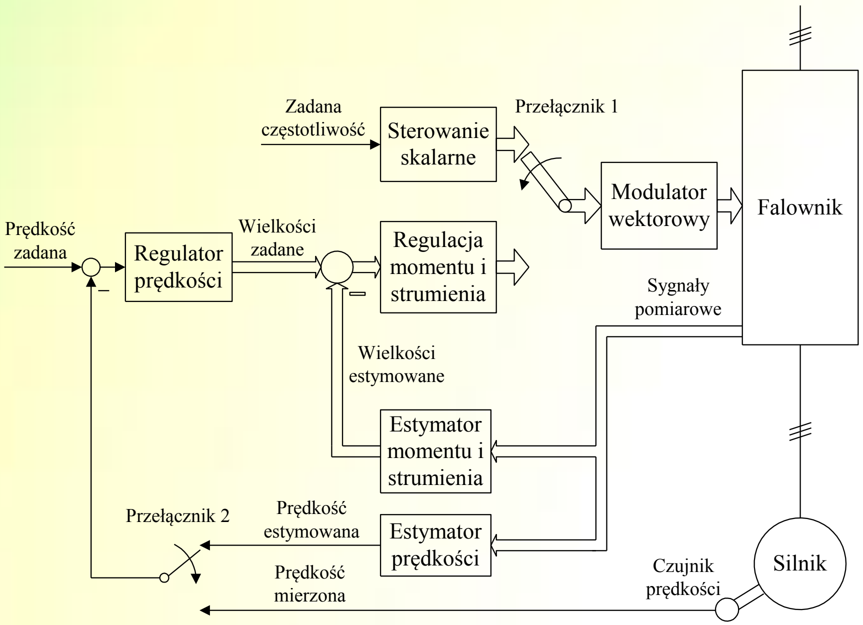

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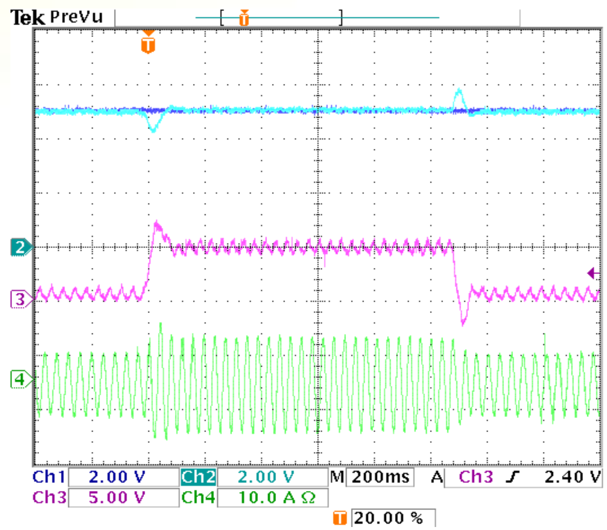

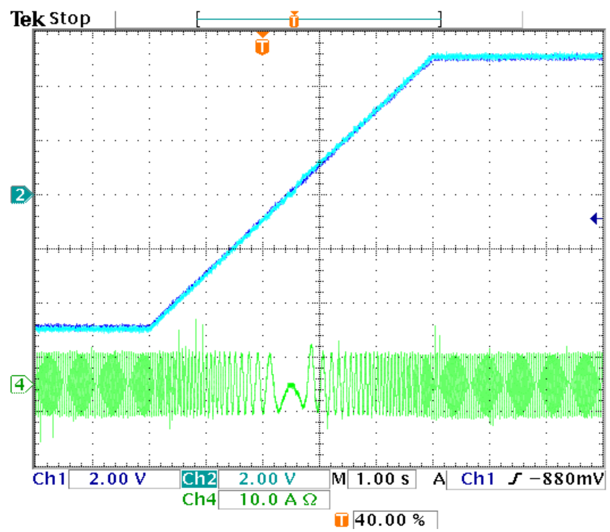

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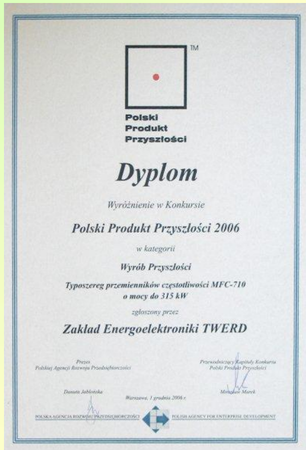

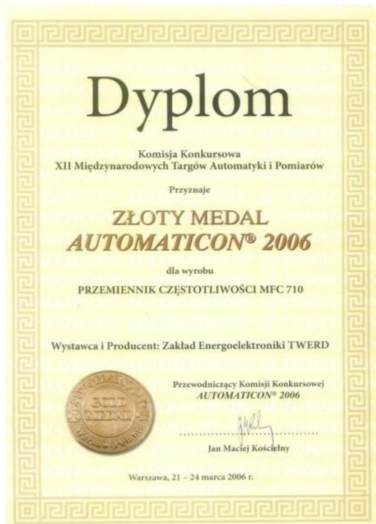

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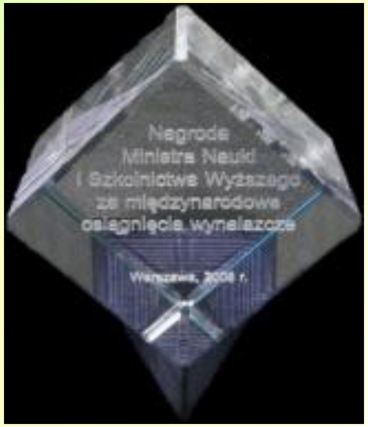

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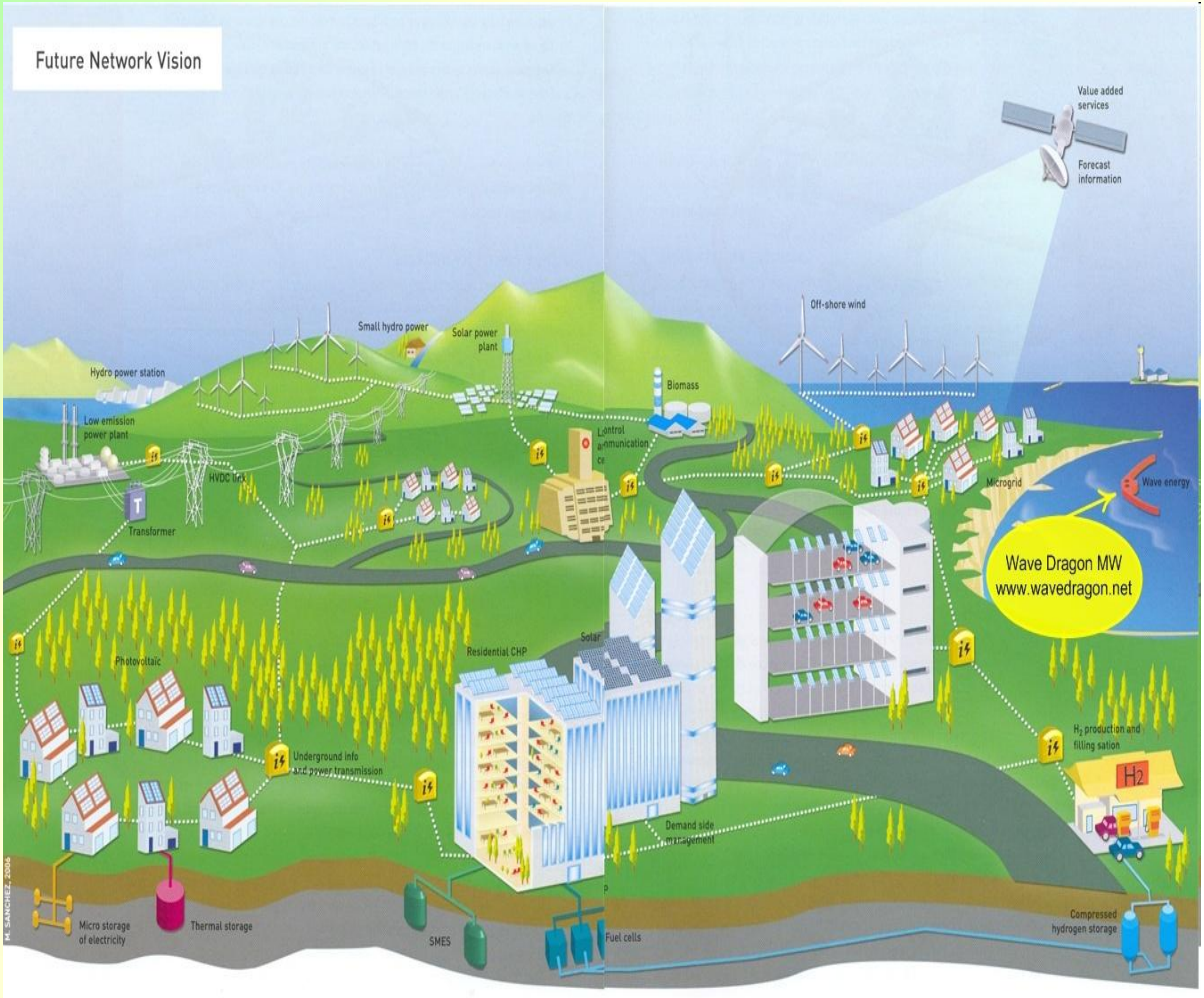

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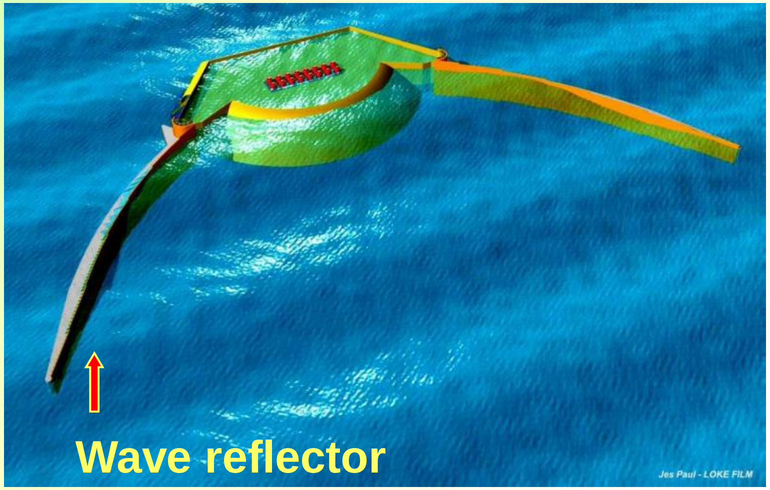
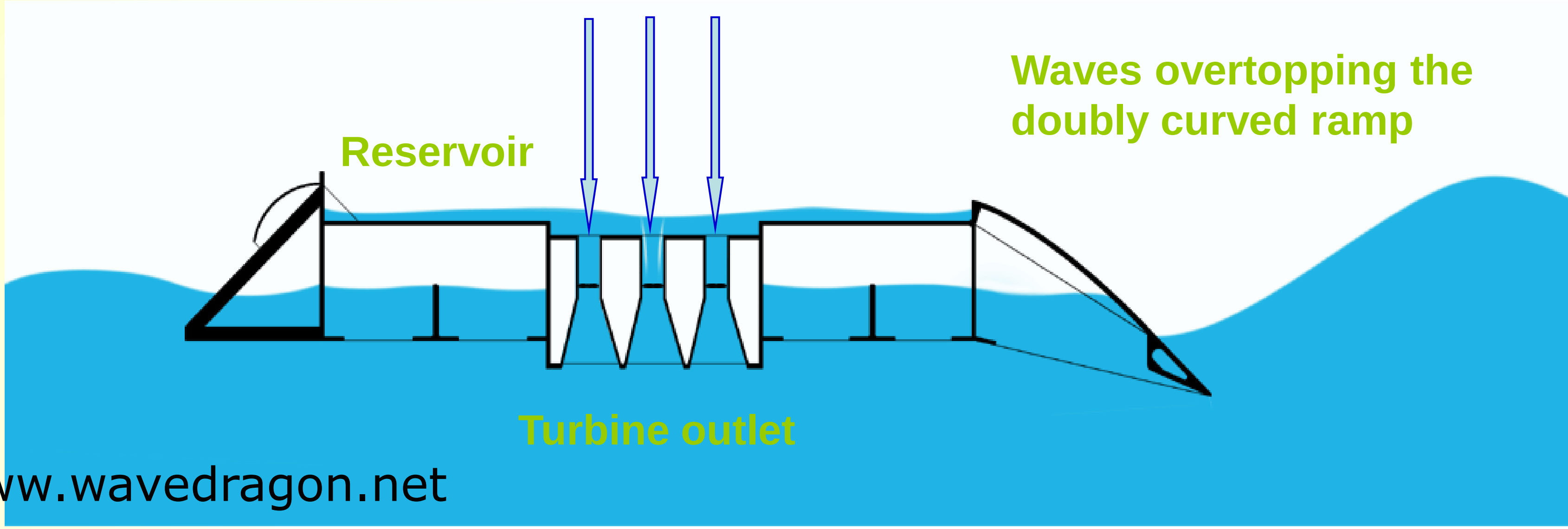
„ Wave Dragon"

Wave Dragon principle

The *Wave Dragon* is a slack-moored wave energy converter that can be deployed alone or in parks wherever a sufficient wave climate and a water depth of more than 25 m is found.



Climate	Power production
24 kW/m	12 GWh/y/unit
36 kW/m	20 GWh/y/unit
48 kW/m	35 GWh/y/unit



www.wavedragon.net

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Wave Dragon **- The 1:4.5 prototype**

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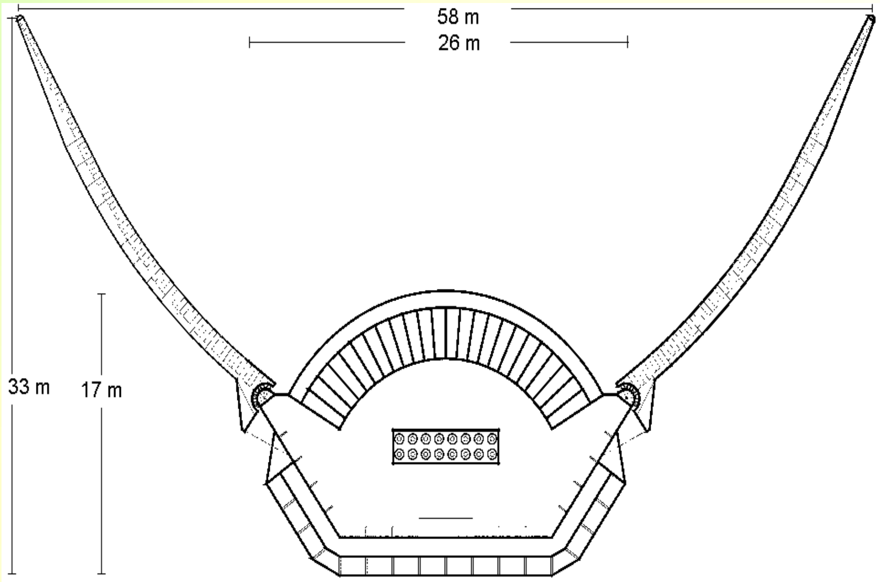

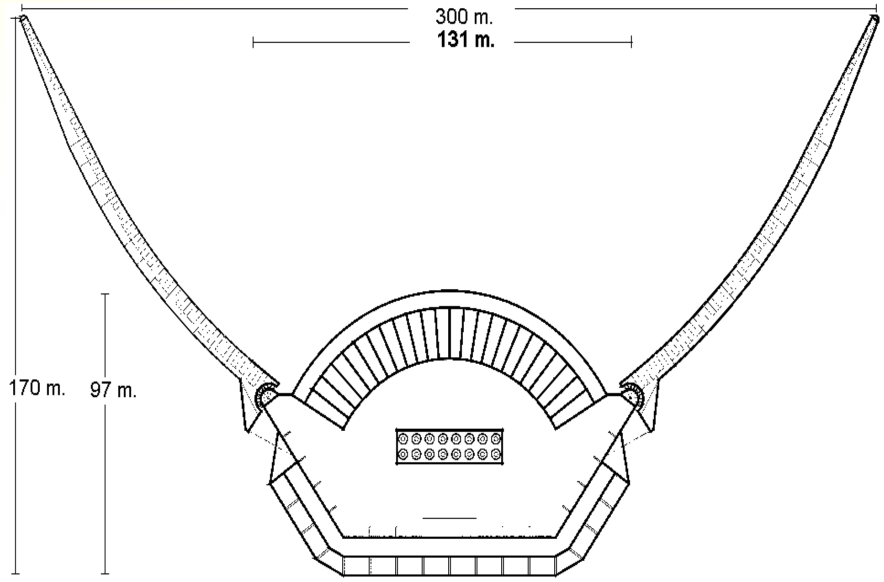

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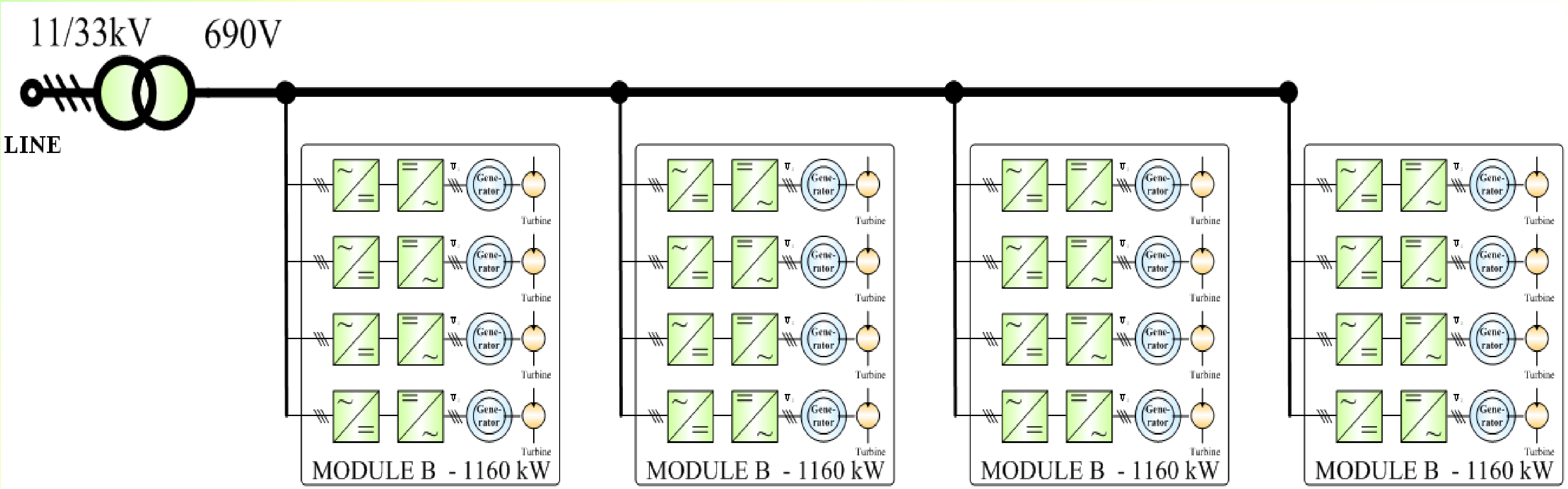

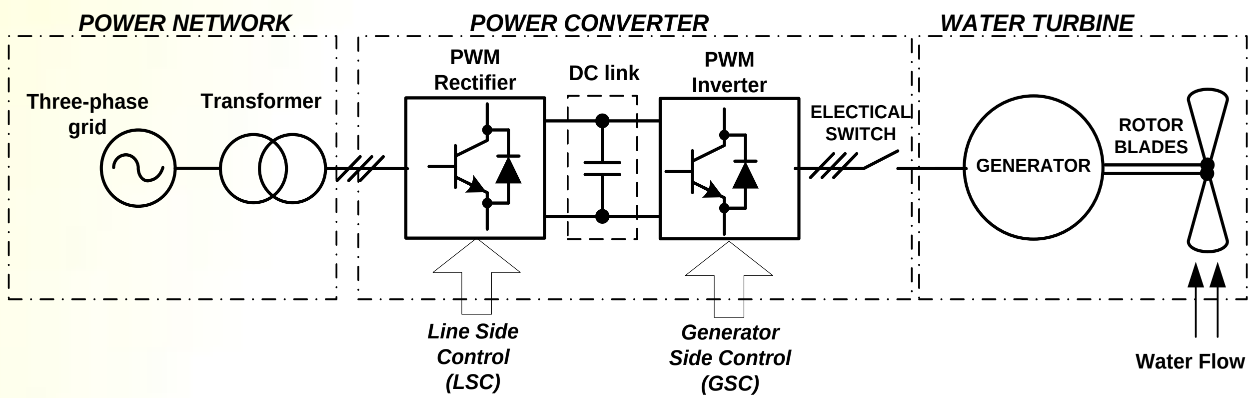

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E-learning Distance Interactive Practical Education,(EDIPE)

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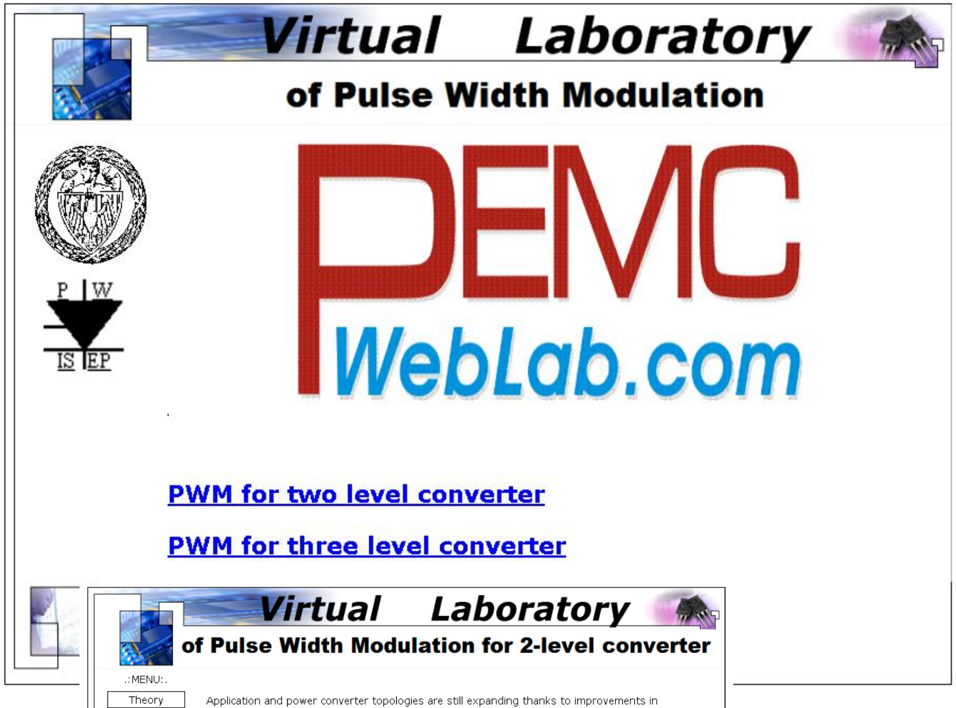


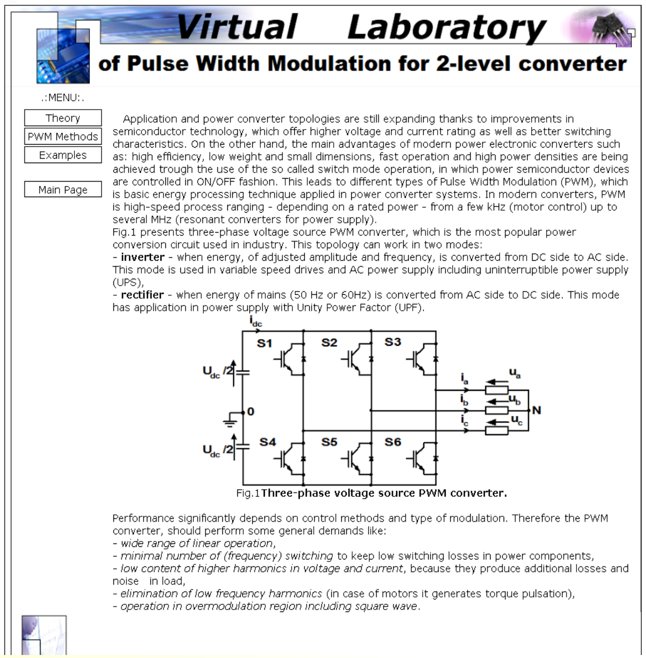
Virtual Laboratory

of Pulse Width Modulation

PEMC WebLab.com

PWM for two level converter

PWM for three level converter



Virtual Laboratory

of Pulse Width Modulation for 2-level converter

.:MENU:.

Theory
PWM Methods
Examples
Main Page

Application and power converter topologies are still expanding thanks to improvements in semiconductor technology, which offer higher voltage and current rating as well as better switching characteristics. On the other hand, the main advantages of modern power electronic converters such as: high efficiency, low weight and small dimensions, fast operation and high power densities are being achieved trough the use of the so called switch mode operation, in which power semiconductor devices are controlled in ON/OFF fashion. This leads to different types of Pulse Width Modulation (PWM), which is basic energy processing technique applied in power converter systems. In modern converters, PWM is high-speed process ranging - depending on a rated power - from a few kHz (motor control) up to several MHz (resonant converters for power supply).

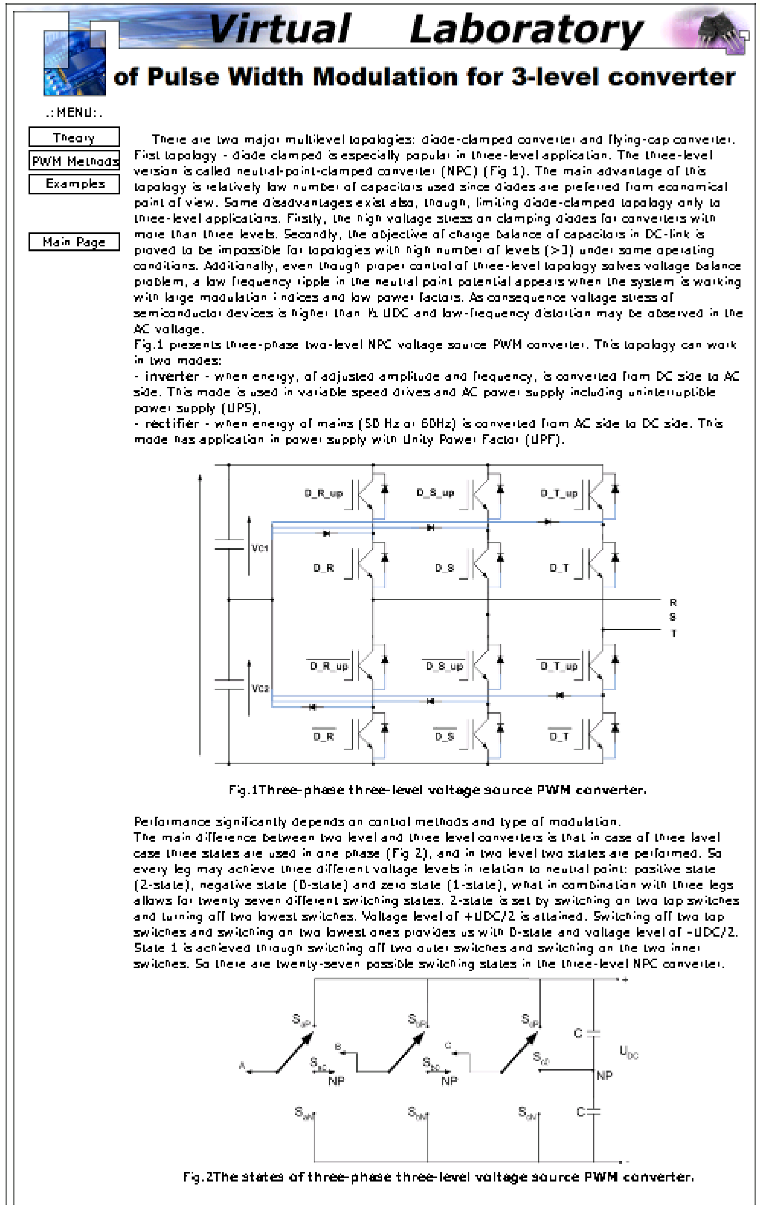
Fig.1 presents three-phase voltage source PWM converter, which is the most popular power conversion circuit used in industry. This topology can work in two modes:

- **inverter** - when energy, of adjusted amplitude and frequency, is converted from DC side to AC side. This mode is used in variable speed drives and AC power supply including uninterruptible power supply (UPS),
- **rectifier** - when energy of mains (50 Hz or 60Hz) is converted from AC side to DC side. This mode has application in power supply with Unity Power Factor (UPF).

Fig.1 **Three-phase voltage source PWM converter.**

Performance significantly depends on control methods and type of modulation. Therefore the PWM converter, should perform some general demands like:

- *wide range of linear operation*,
- *minimal number of (frequency) switching* to keep low switching losses in power components,
- *low content of higher harmonics in voltage and current*, because they produce additional losses and noise in load,
- *elimination of low frequency harmonics* (in case of motors it generates torque pulsation),
- *operation in overmodulation region including square wave*.



Virtual Laboratory

of Pulse Width Modulation for 3-level converter

.:MENU:.

Theory
PWM Methods
Examples
Main Page

There are two major multilevel topologies: diode-clamped converter and flying-cap converter. First topology - diode clamped is especially popular in three-level application. The three-level version is called neutral-point-clamped converter (NPC) (Fig 1). The main advantage of this topology is relatively low number of capacitors used since diodes are preferred from economical point of view. Some disadvantages exist also, though, limiting diode-clamped topology only to three-level applications. Firstly, the high voltage stress on clamping diodes for converters with more than three levels. Secondly, the objective of charge balance of capacitors in DC-link is proved to be impossible for topologies with high number of levels (>3) under some operating conditions. Additionally, even though proper control of three-level topology solves voltage balance problem, a low frequency ripple in the neutral point potential appears when the system is working with large modulation indices and low power factors. As consequence voltage stress of semiconductor devices is higher than ½ UDC and low-frequency distortion may be observed in the AC voltage.

Fig.1 presents three-phase two-level NPC voltage source PWM converter. This topology can work in two modes:

- inverter - when energy, of adjusted amplitude and frequency, is converted from DC side to AC side. This mode is used in variable speed drives and AC power supply including uninterruptible power supply (UPS),
- rectifier - when energy of mains (50 Hz or 60Hz) is converted from AC side to DC side. This mode has application in power supply with Unity Power Factor (UPF).

Fig.1 Three-phase three-level voltage source PWM converter.

Performance significantly depends on control methods and type of modulation.

The main difference between two level and three level converters is that in case of three level case three states are used in one phase (Fig 2), and in two level two states are performed. So every leg may achieve three different voltage levels in relation to neutral point: positive state (2-state), negative state (0-state) and zero state (1-state), what in combination with three legs allows for twenty seven different switching states. 2-state is set by switching on two top switches and turning off two lowest switches. Voltage level of +UDC/2 is attained. Switching off two top switches and switching on two lowest ones provides us with 0-state and voltage level of -UDC/2. State 1 is achieved through switching off two outer switches and switching on the two inner switches. So there are twenty-seven possible switching states in the three-level NPC converter.

Fig.2 The states of three-phase three-level voltage source PWM converter.

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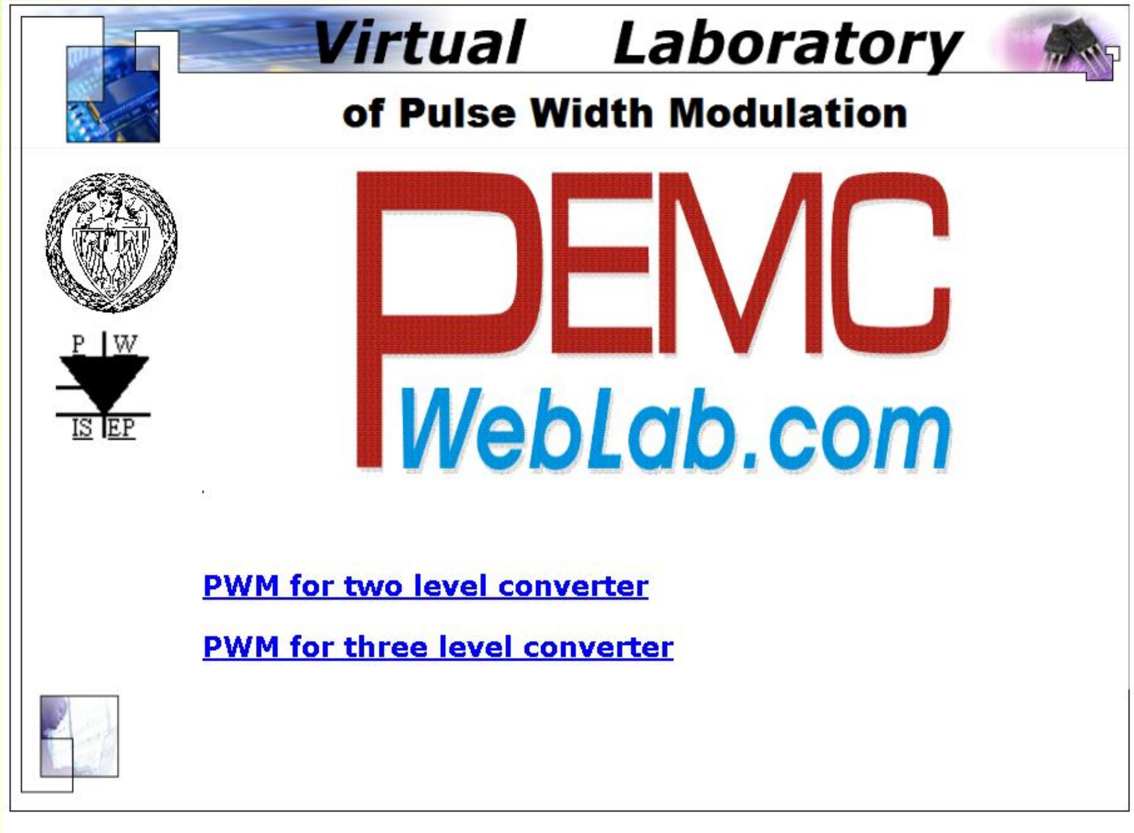

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„New direct power control for three-level DC/AC converter applied for wind turbine”

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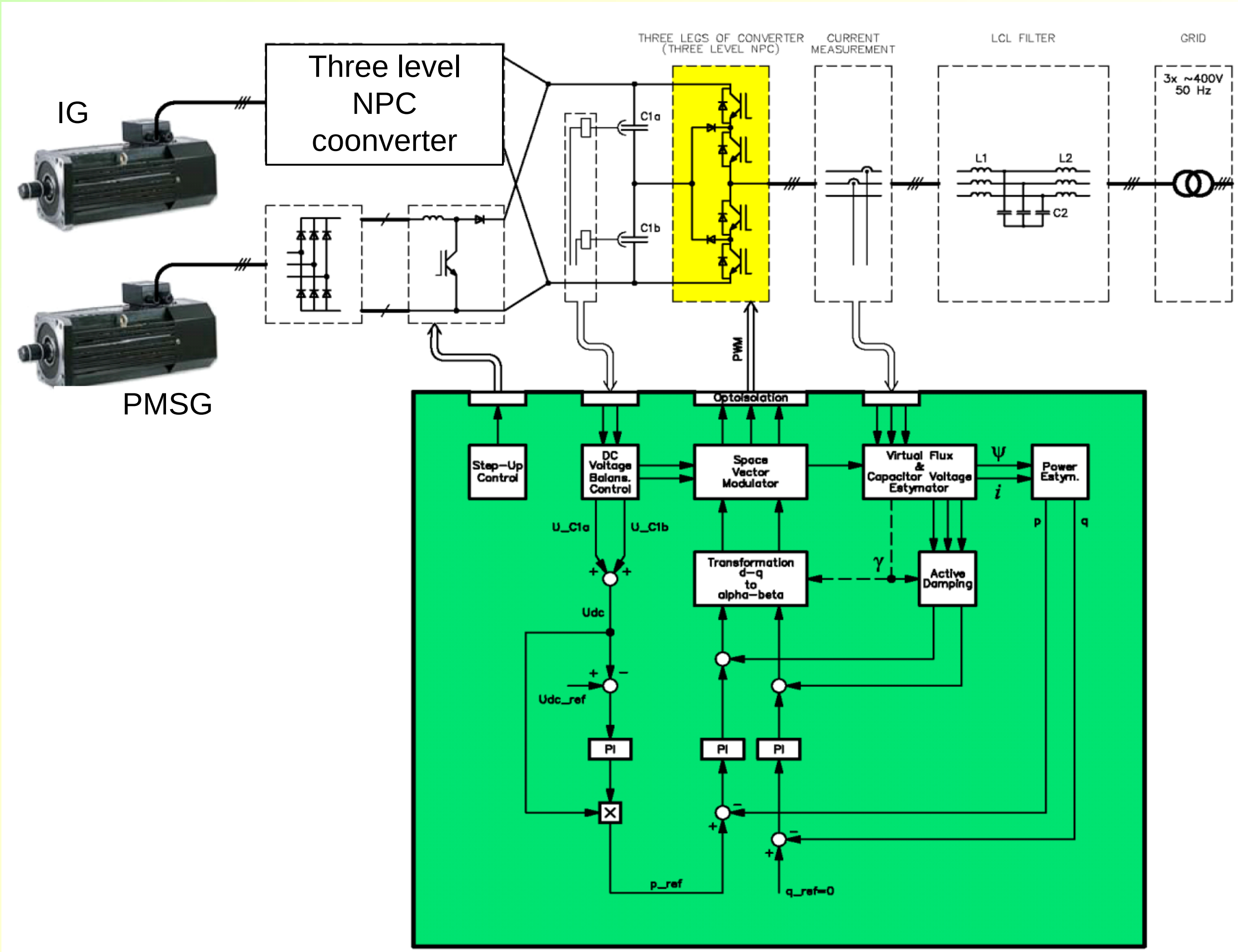

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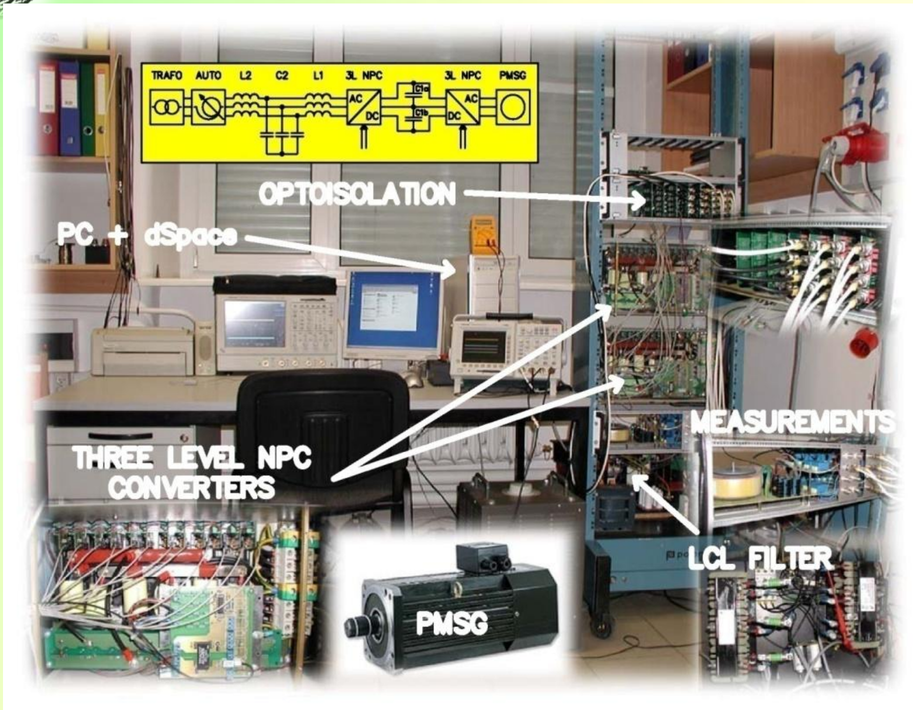
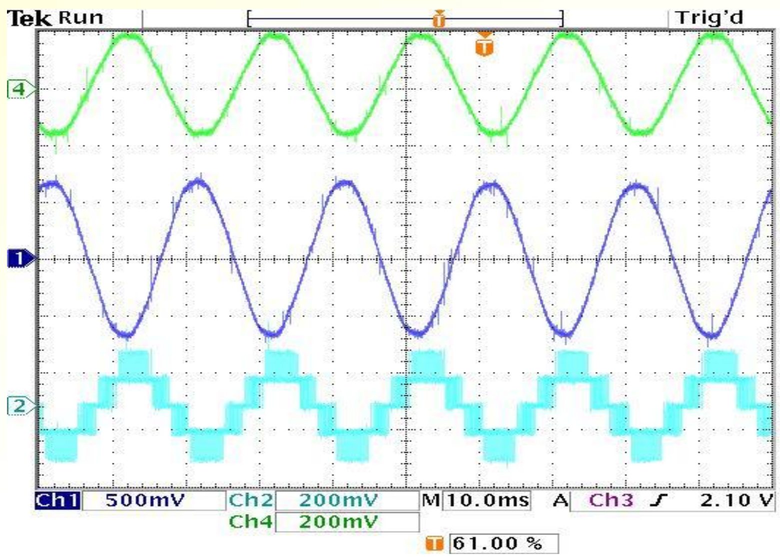
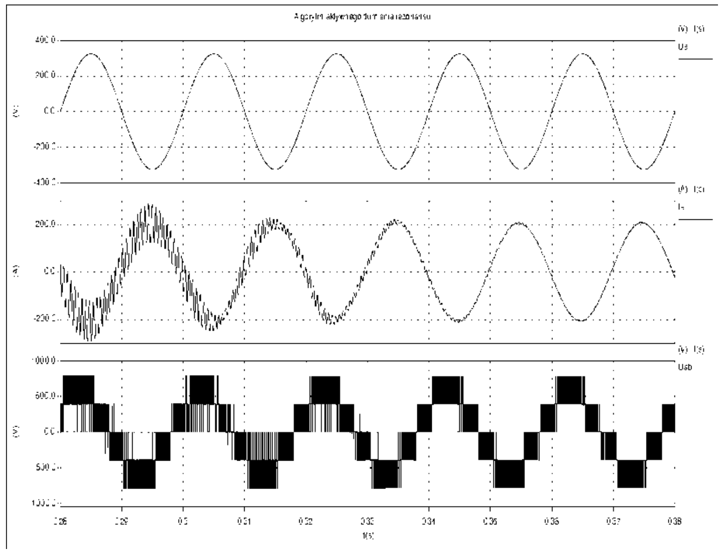




Region	Classical SVM	Adaptive SVM	
		Typical	Maximum
1	6	4	7
2	8	4	7
3	6	4	7
4	12	4	7



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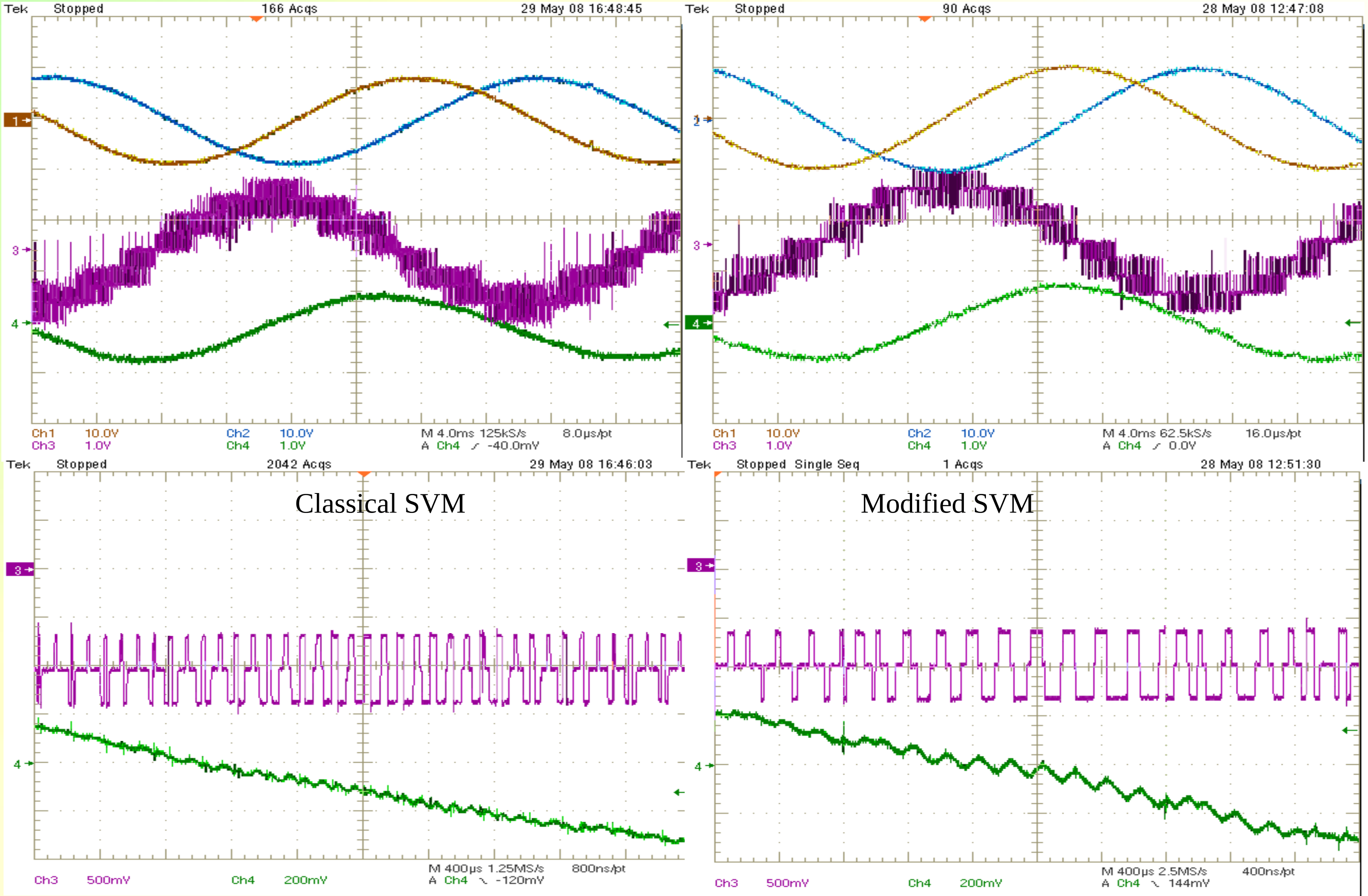

From the top: $\Psi_{S\alpha}$, $\Psi_{S\beta}$ [1Wb/div] Voltage U_{SA} [100V/div], Phase current I_{SA} [10A/div]
Zoom: Voltage U_{SA} [50V/div], Phase current I_{SA} [2A/dz]

Marek Jasinski

„ New direct power control for three-level DC/AC converter applied for wind turbine”

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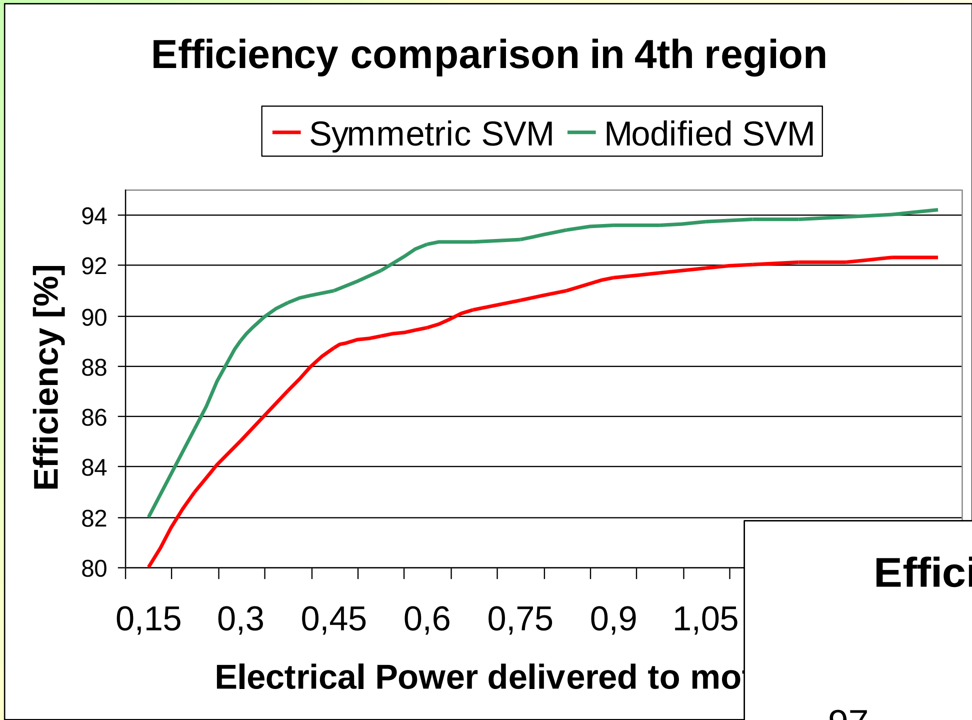

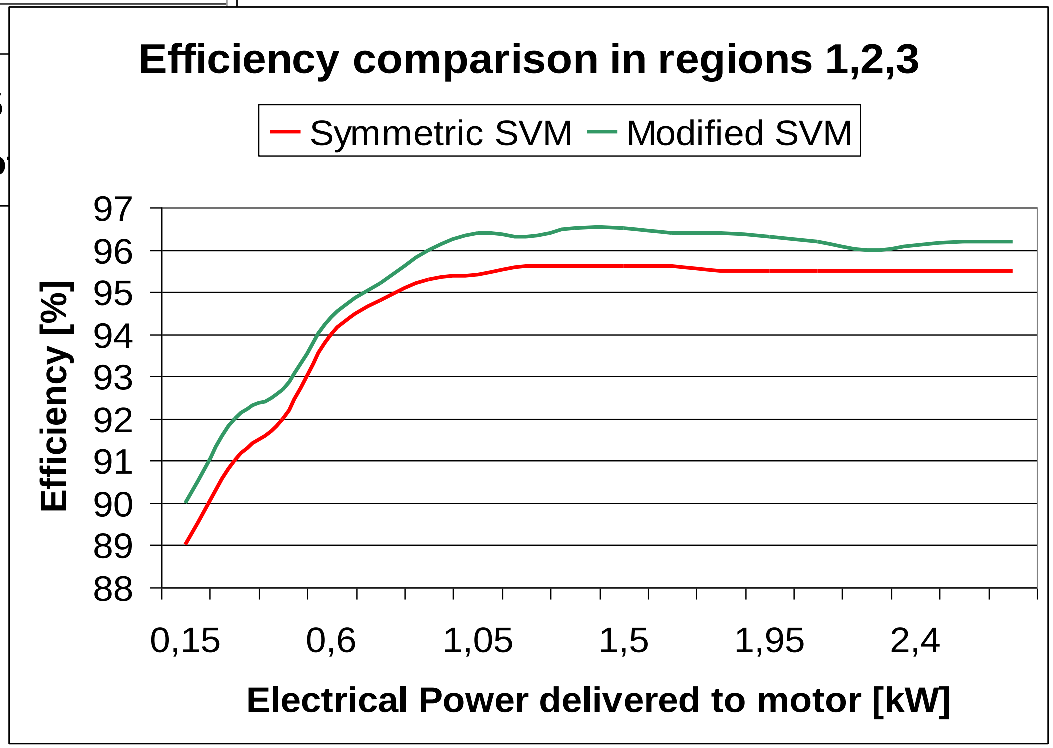

Marek Jasinski

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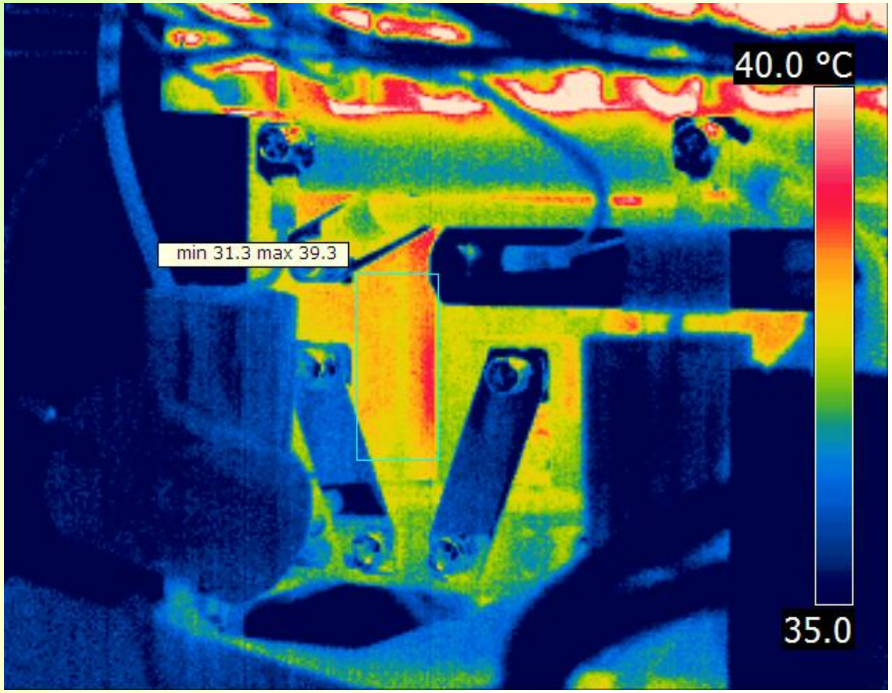
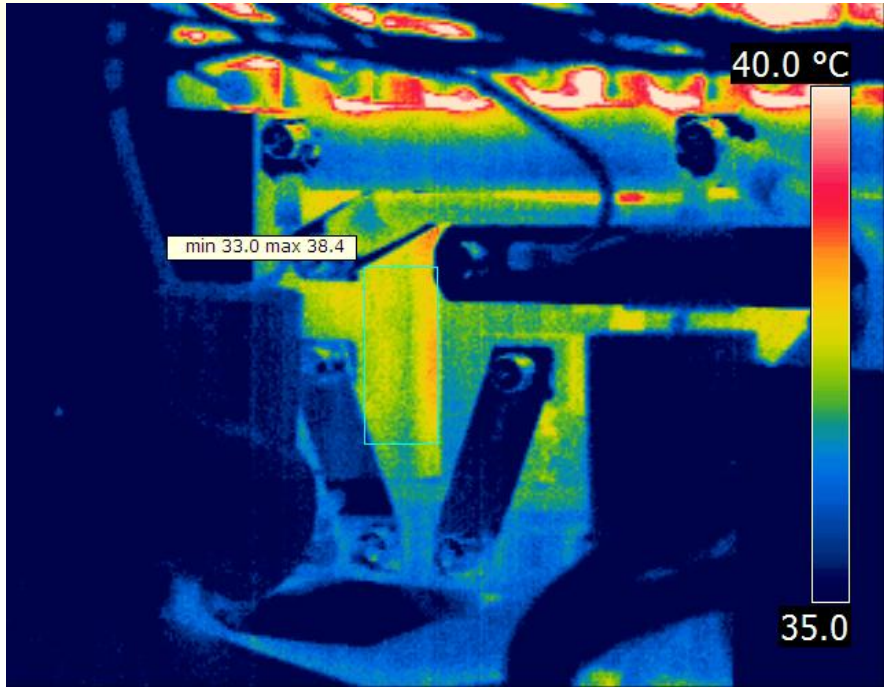


Classical SVM

T_{max}=39.3°C



Modified SVM

T_{max}=38.4°C

Marek Jasinski

„Investigation and elaboration of new cascade topology of sigle-phase multilevel PWM converter”

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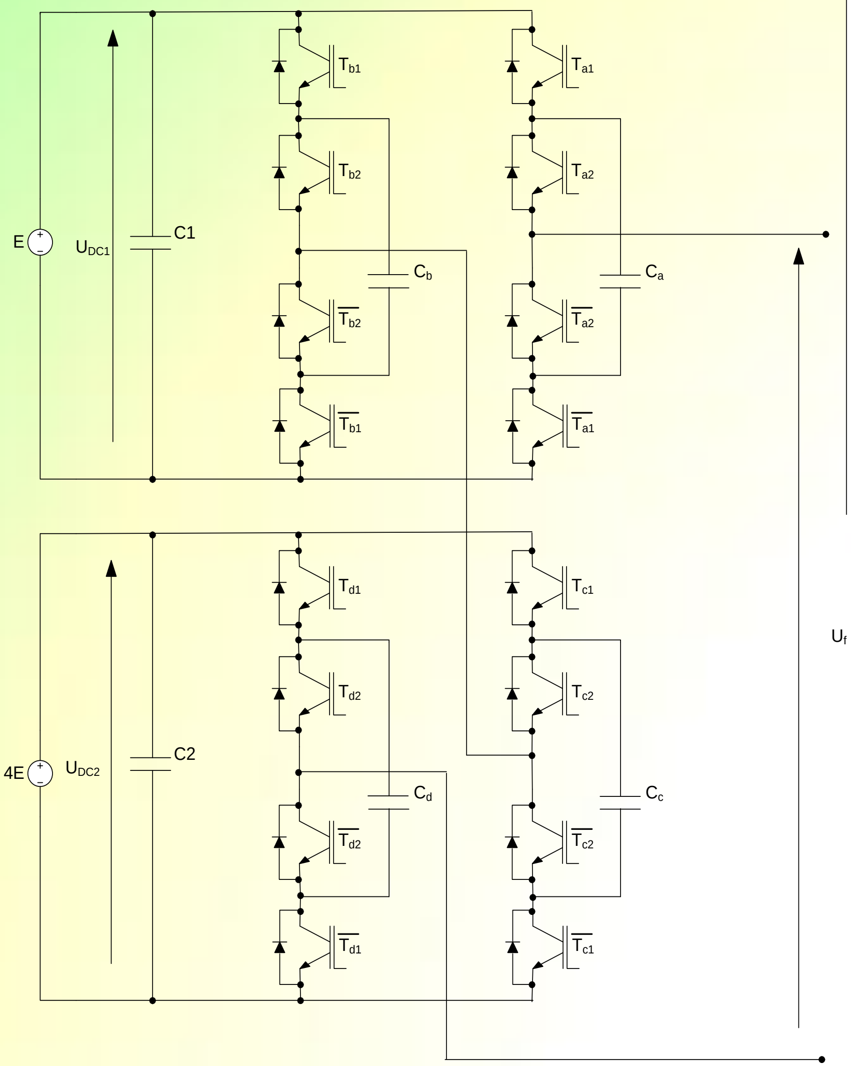
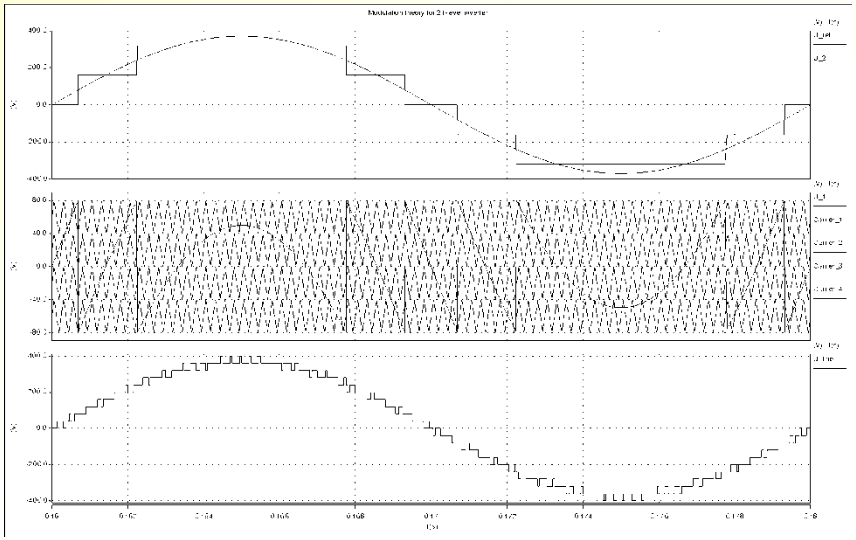
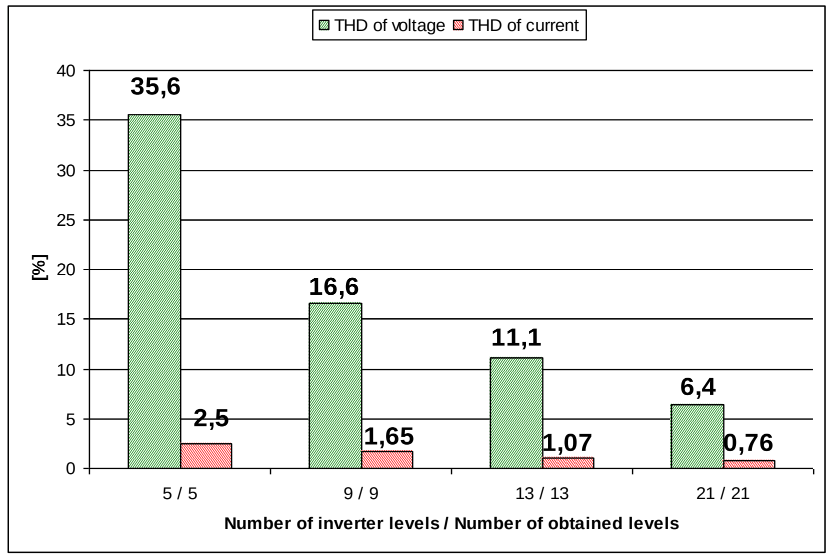
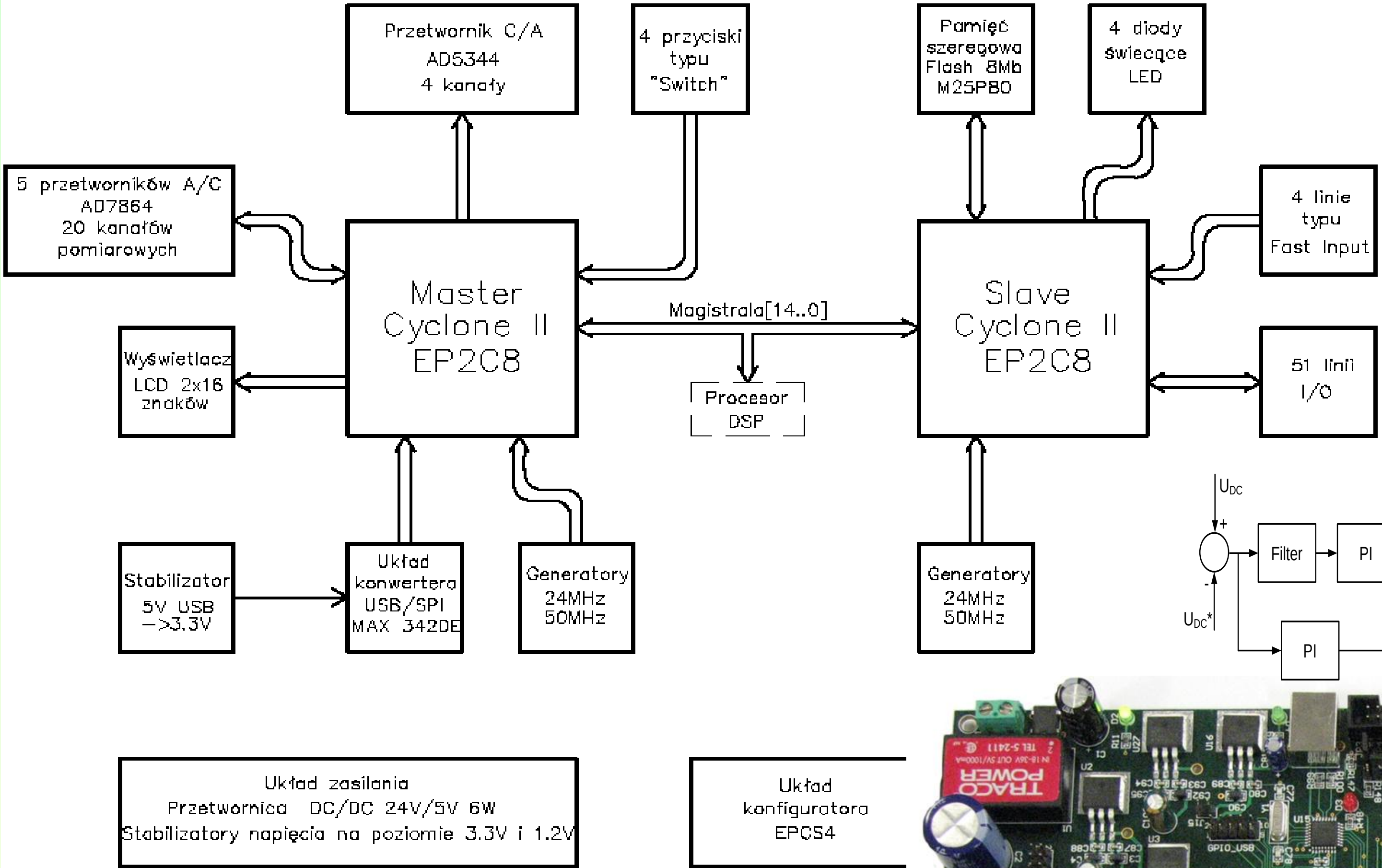


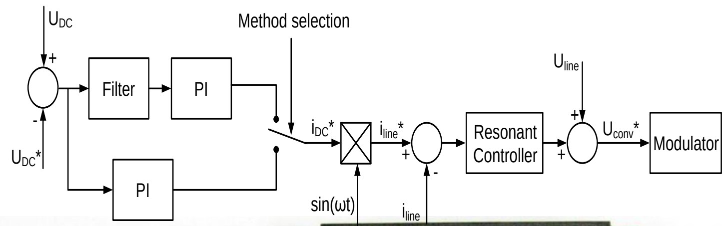


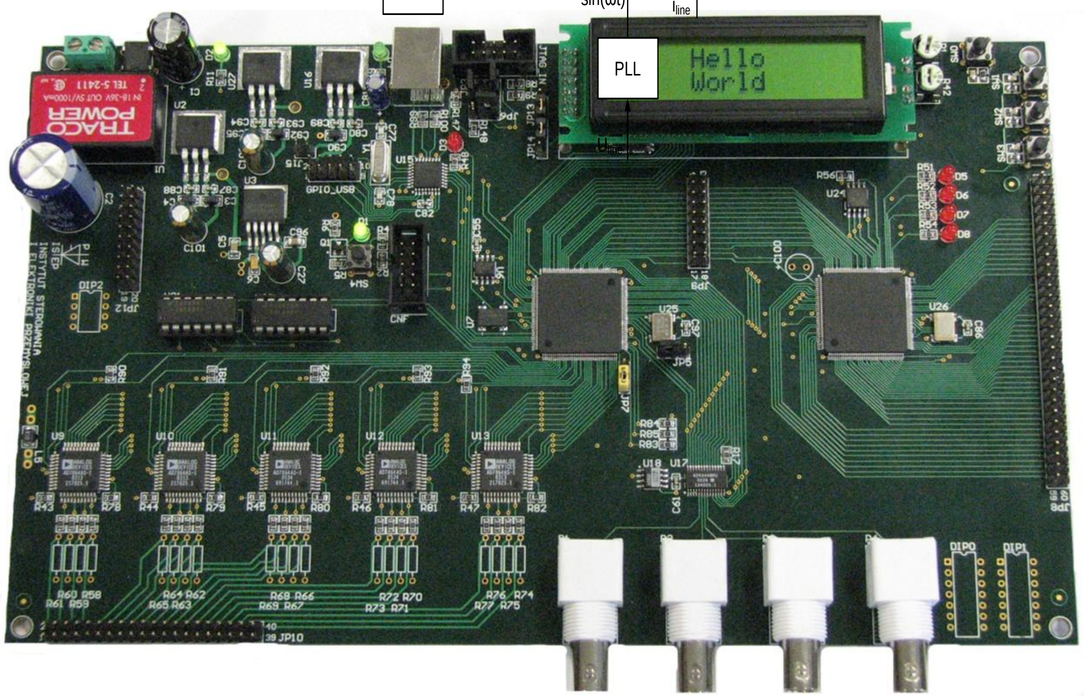


Marek Jasinski

„Investigation and elaboration of new cascade topology of sigle-phase multilevel PWM converter"







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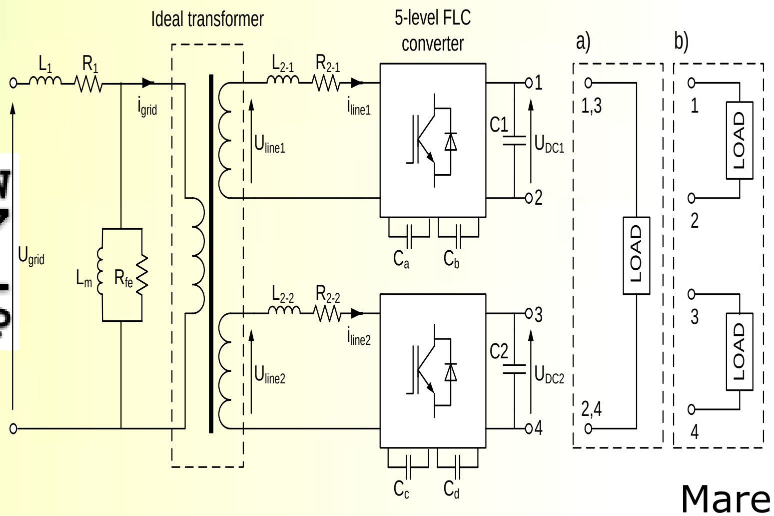

Marek Jasinski

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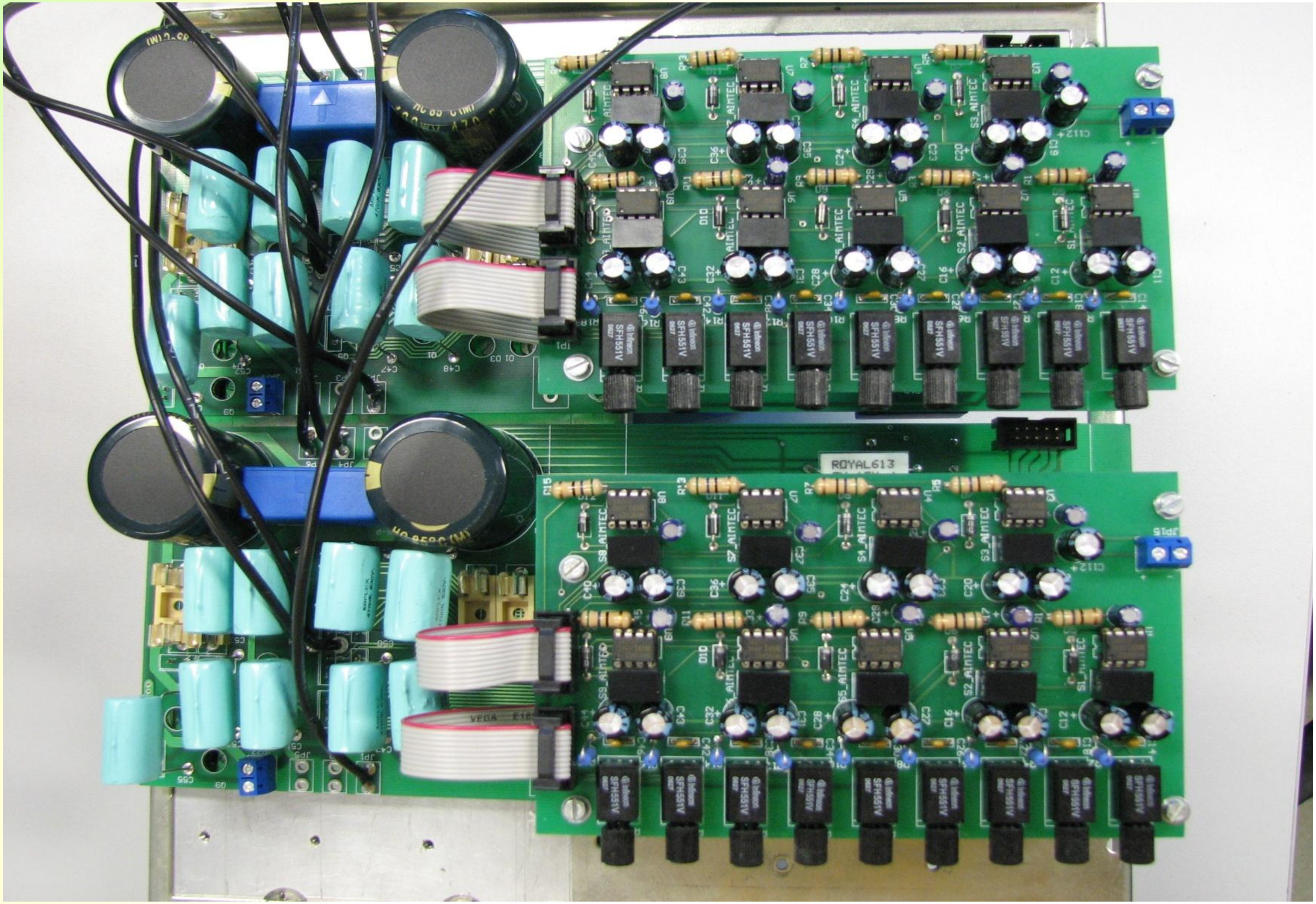

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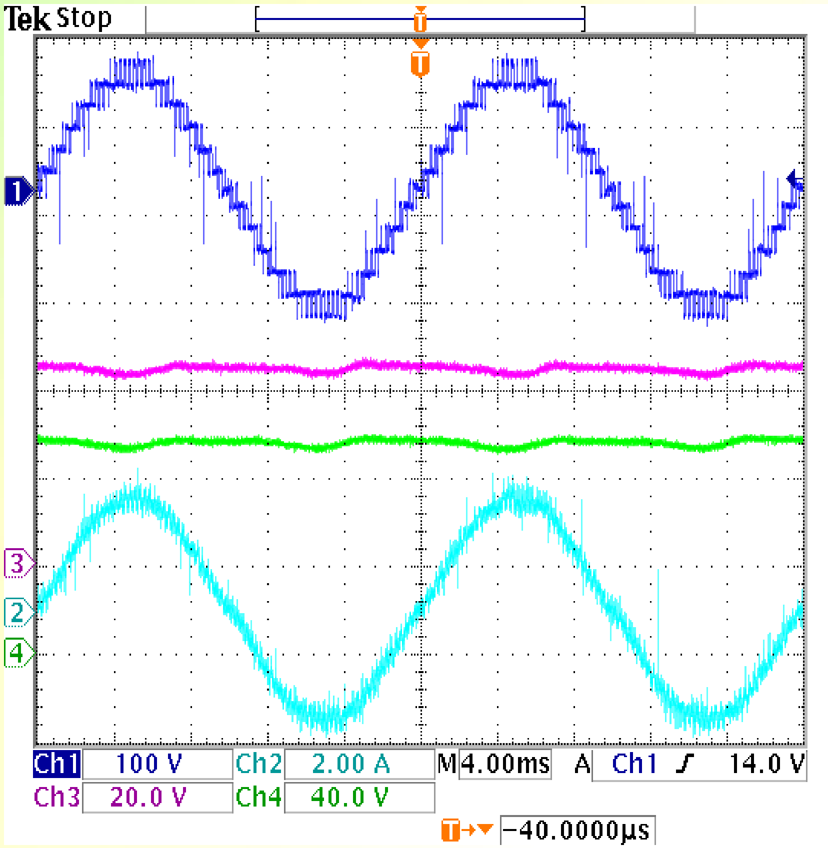

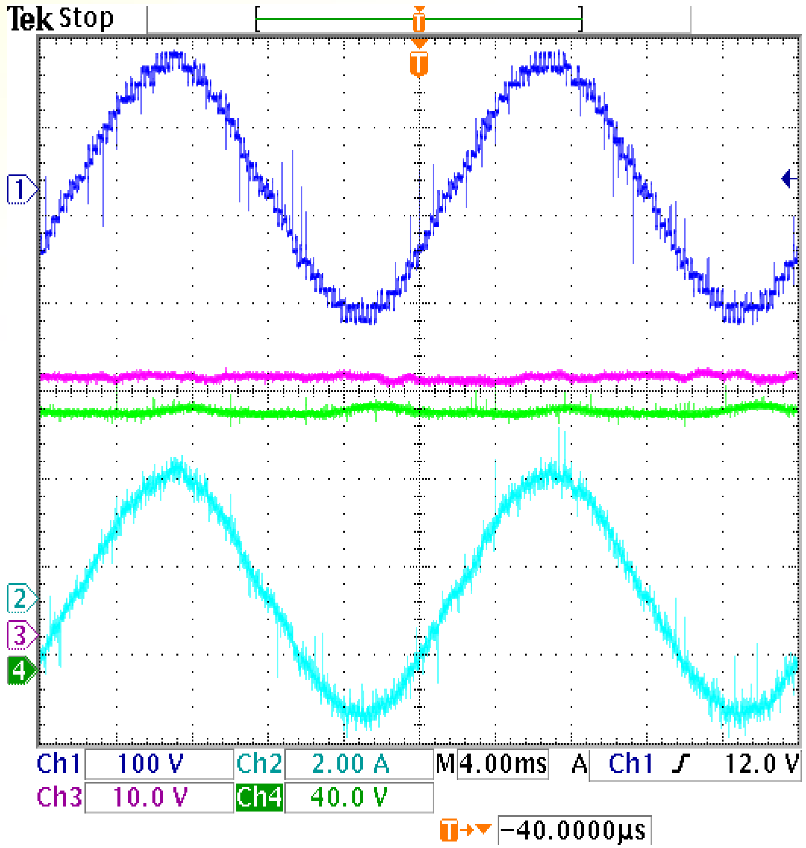

Marek Jasinski

„ Investigation and elaboration of new cascade topology of sigle-phase multilevel PWM converter”

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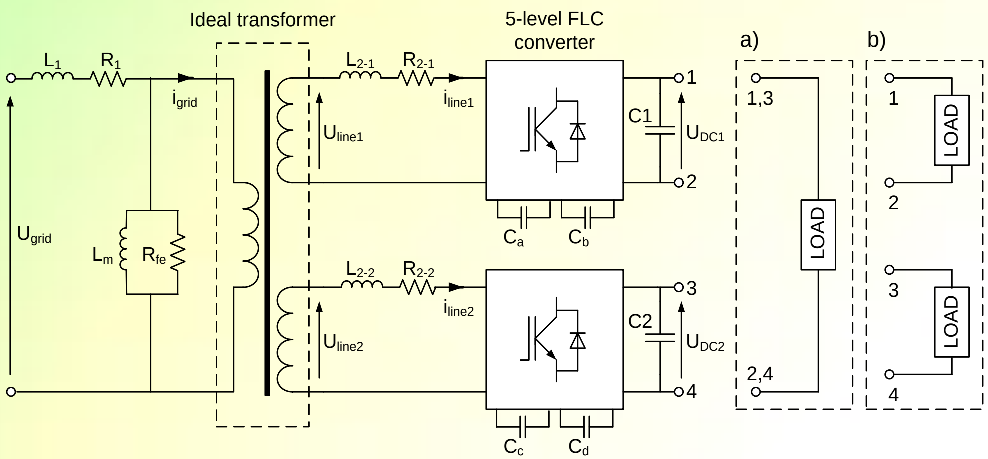
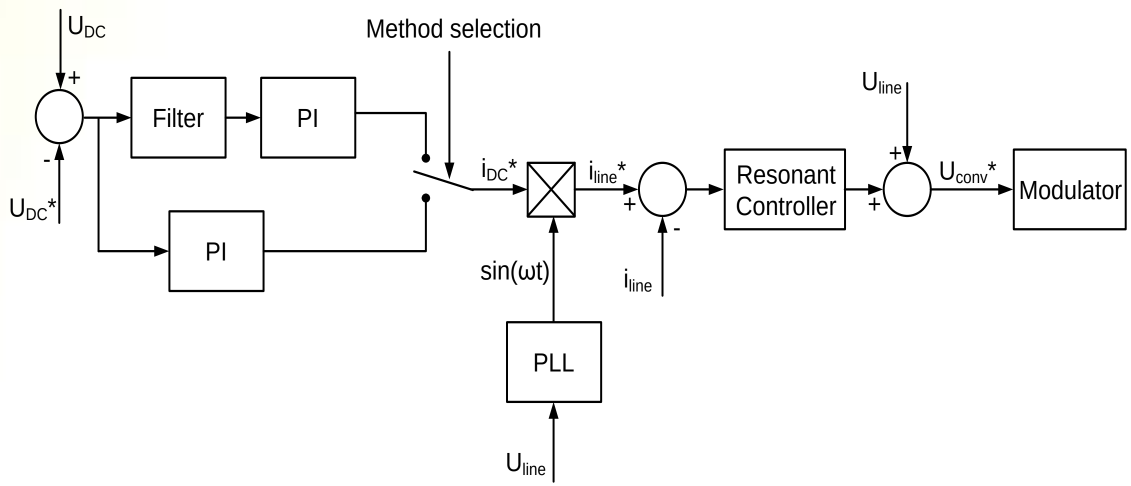
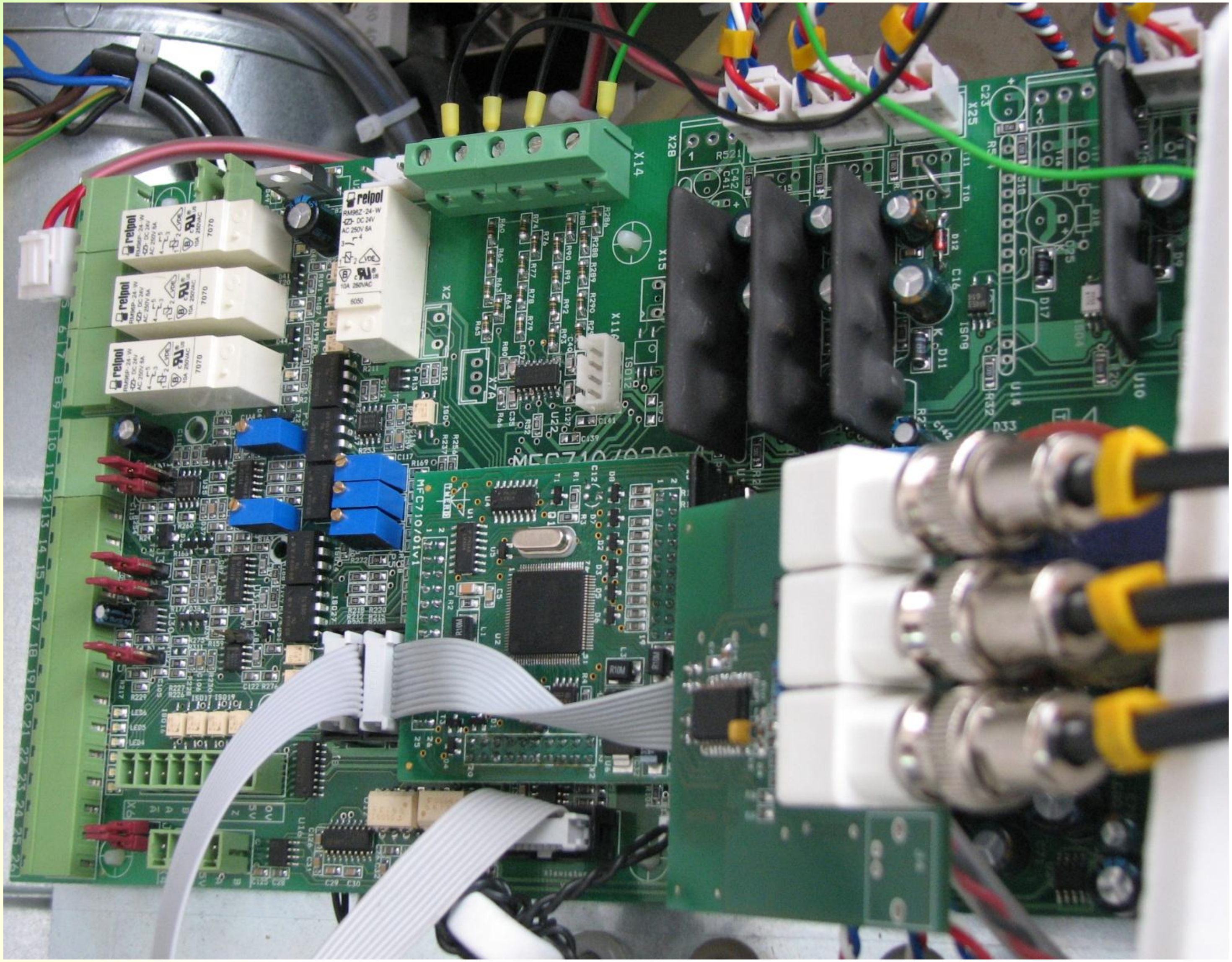




Marek Jasinski

„ Direct Power Control Space Vector Modulated for Three-Phase PWM rectifier (55kW-300kW)”

Industrial project



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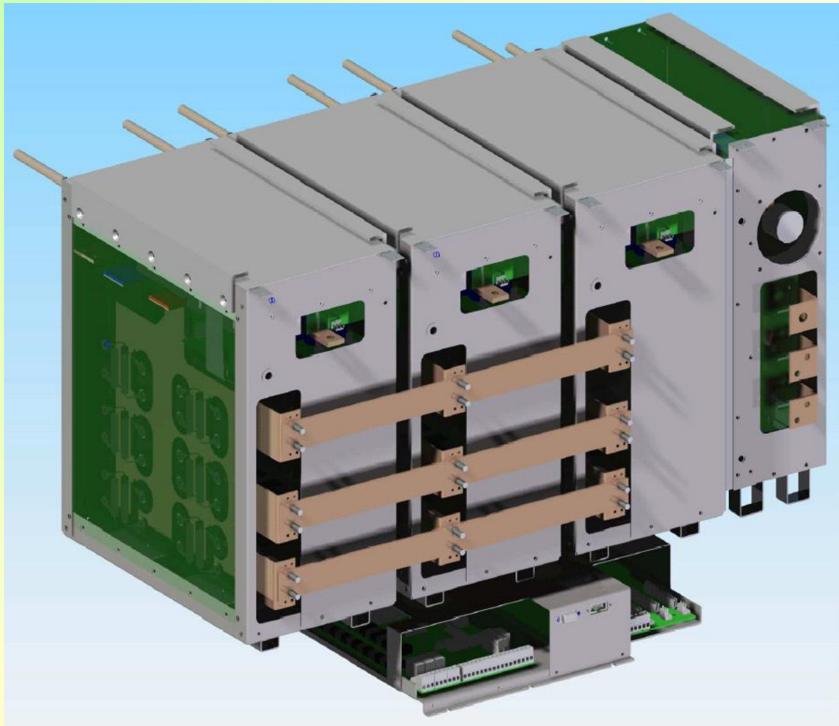
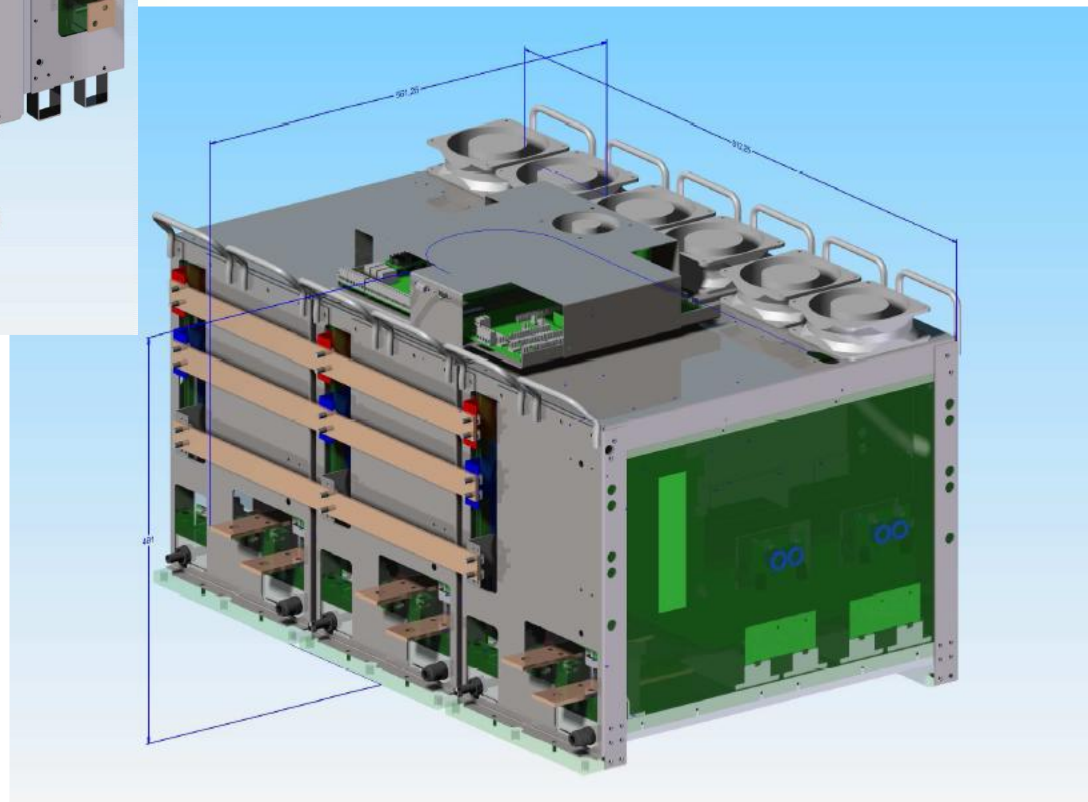
Marek Jasinski

Twerd - **Three-level npc inverter**
MFC810M (250 – 630 kW; 1140 V)

Industrial project





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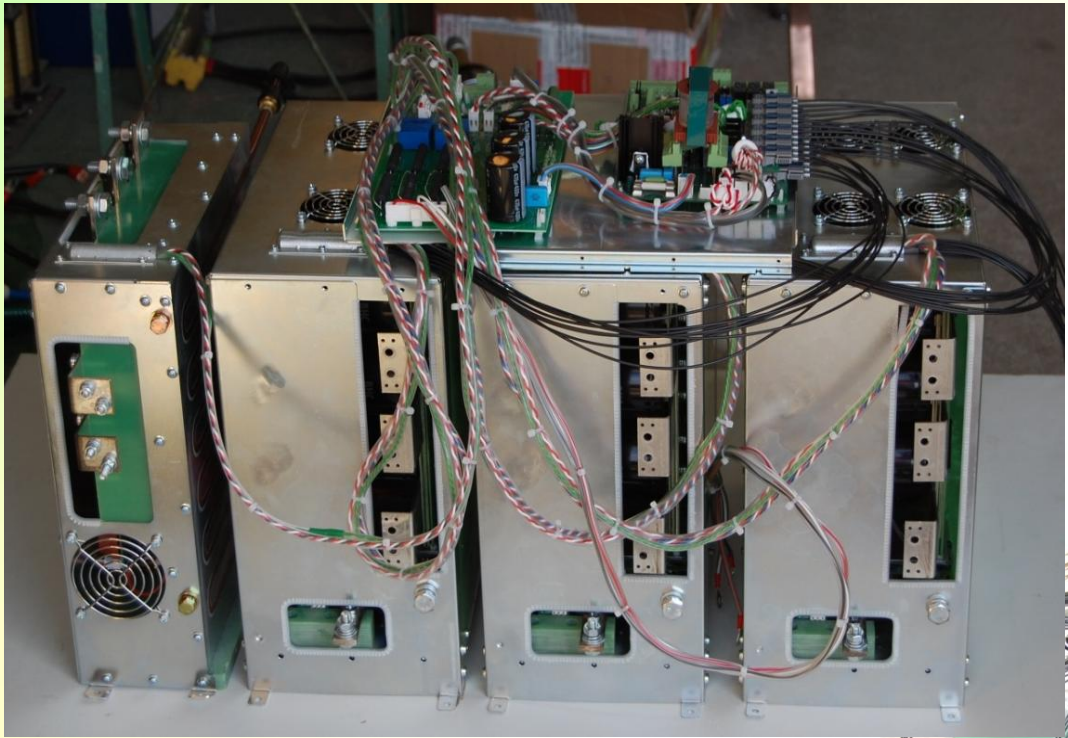
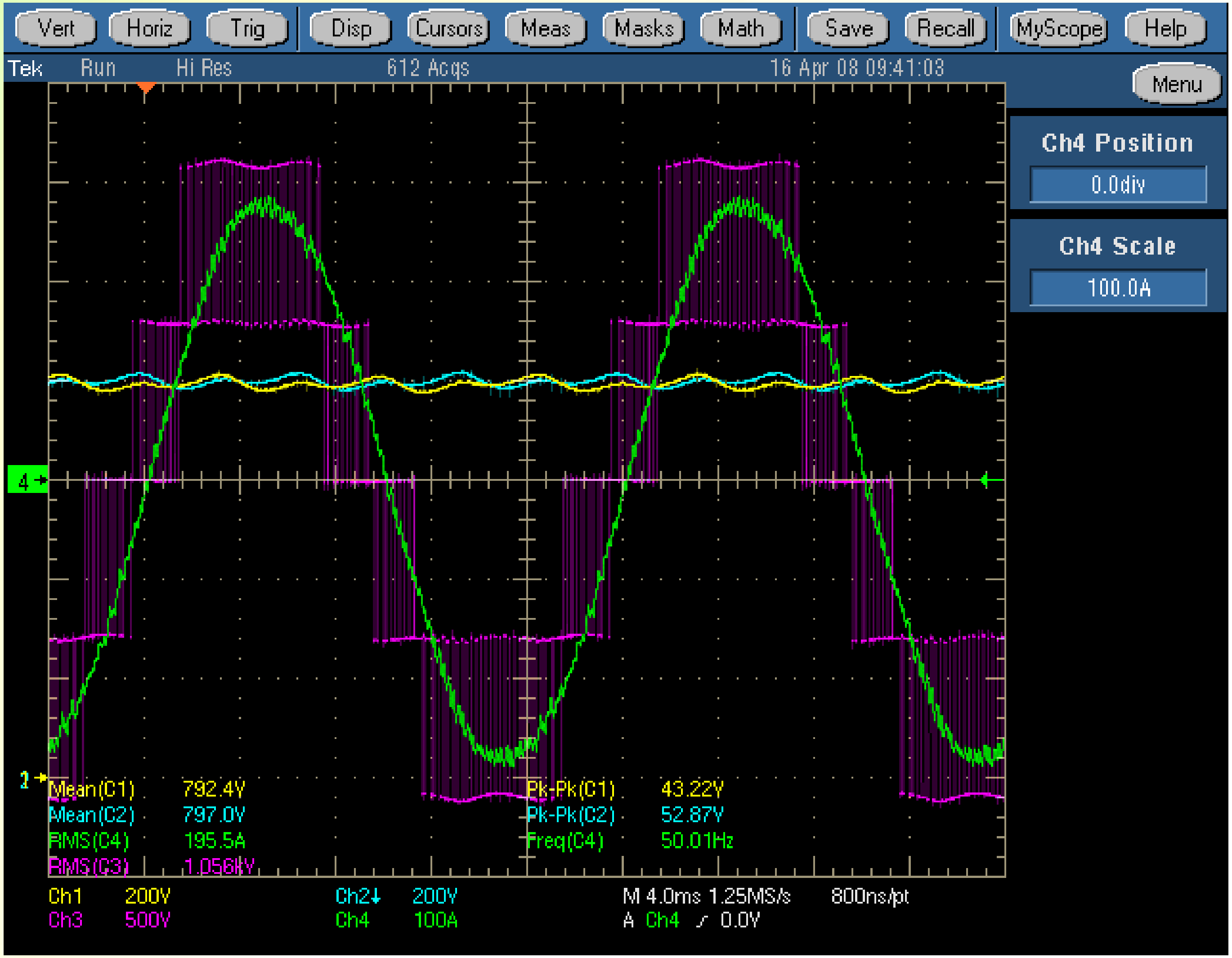


Twerd - **Three-level npc inverter**
MFC810M (250 – 630 kW; 1140 V)
Industrial project



Steady steate operation at output frequency 50Hz and phase current 200A

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Twerd - **Three-level npc inverter**
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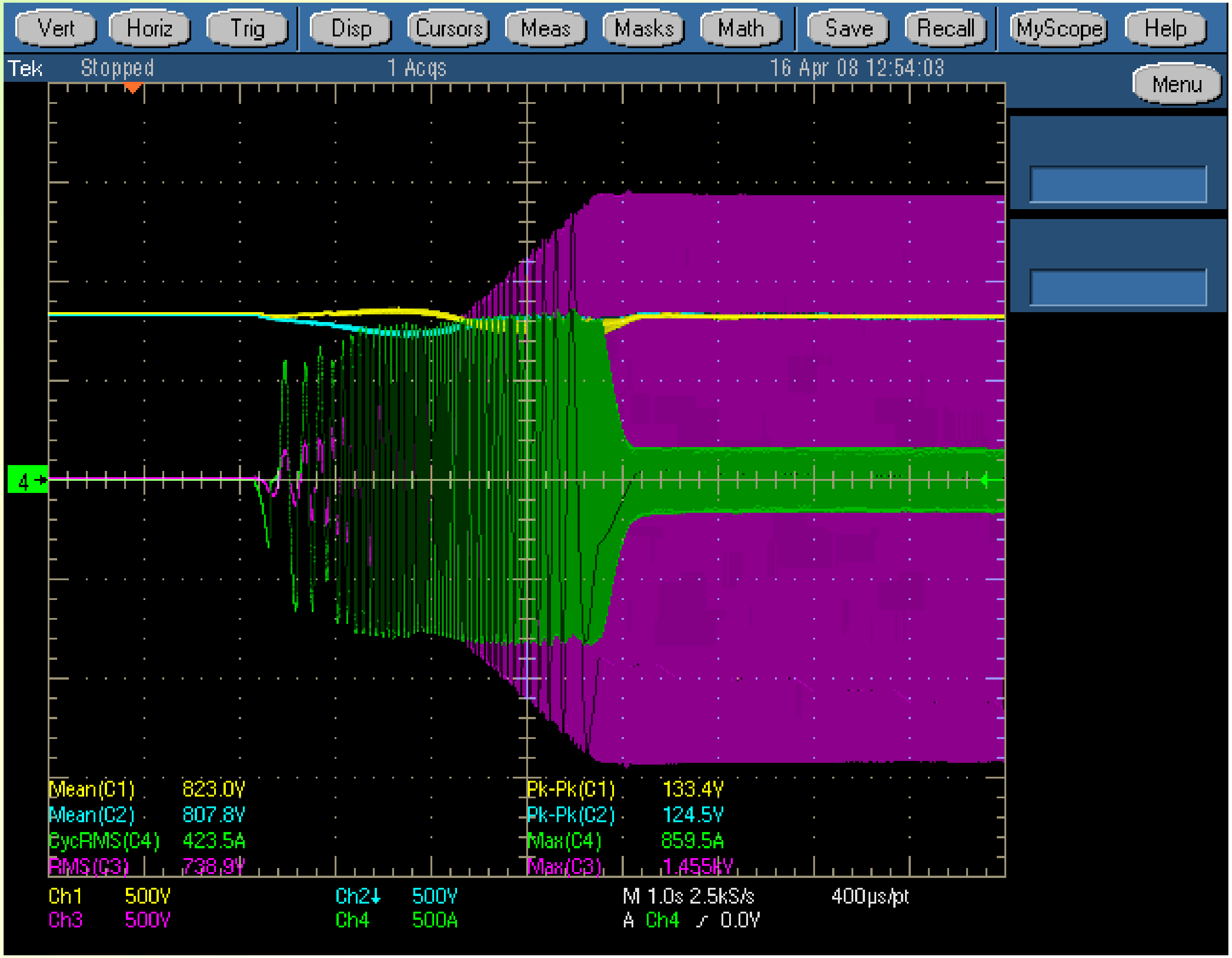

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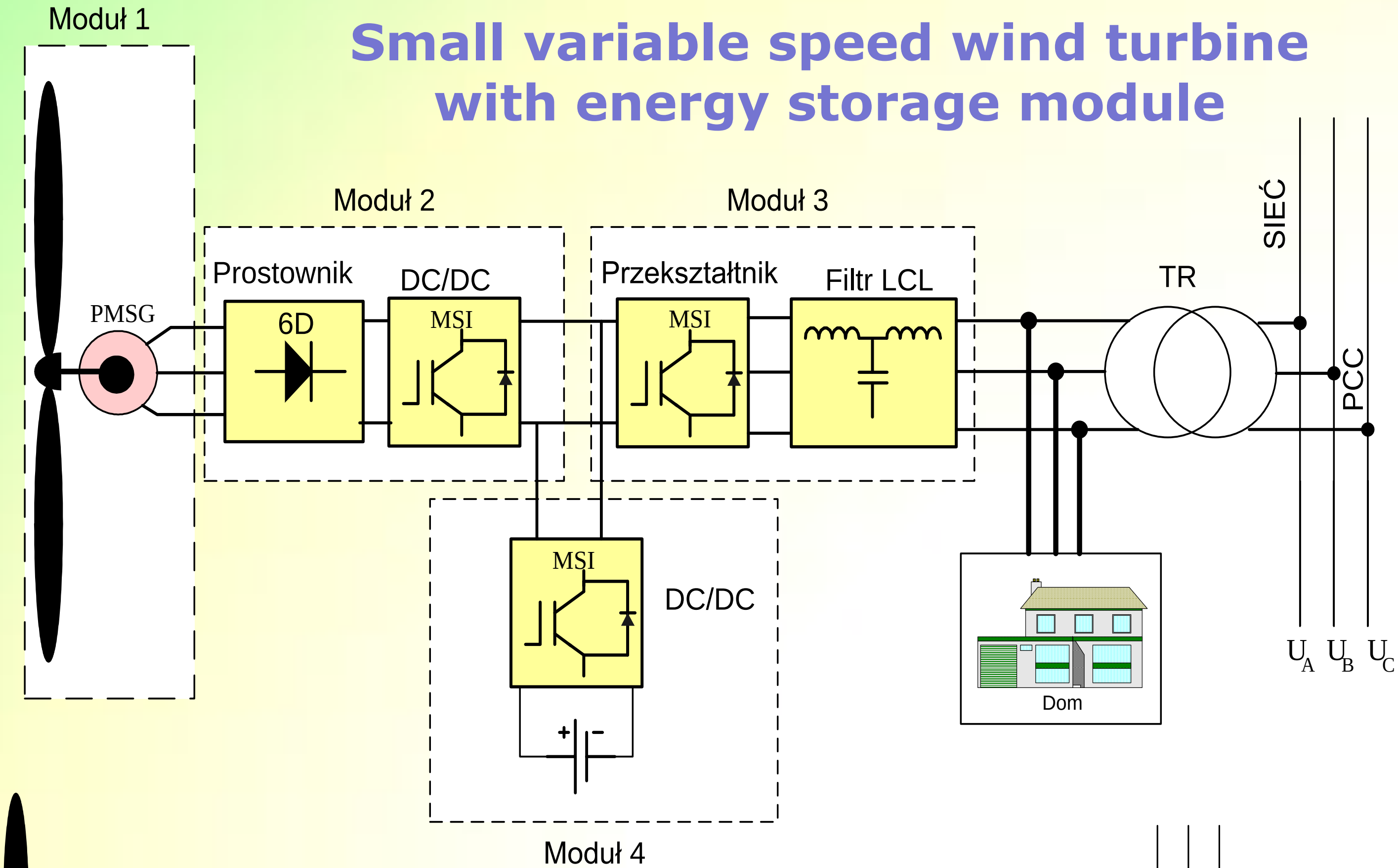
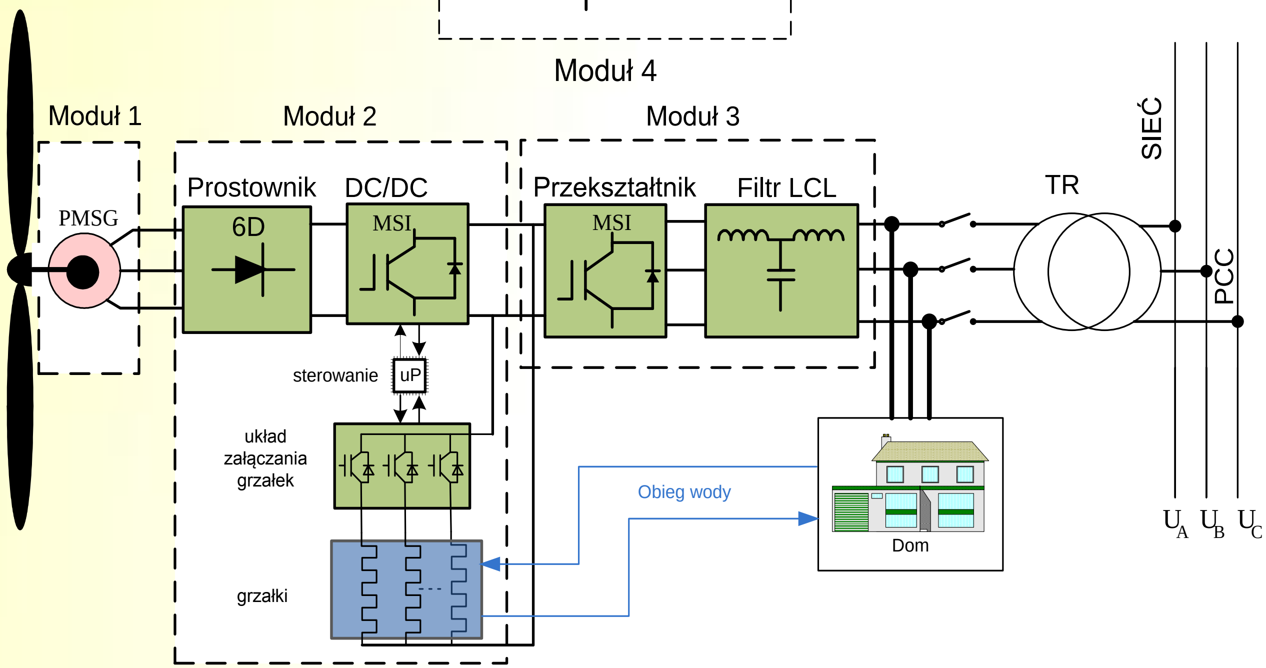
Marek Jasinski

Small variable speed wind turbine with energy storage module





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Marek Jasinski

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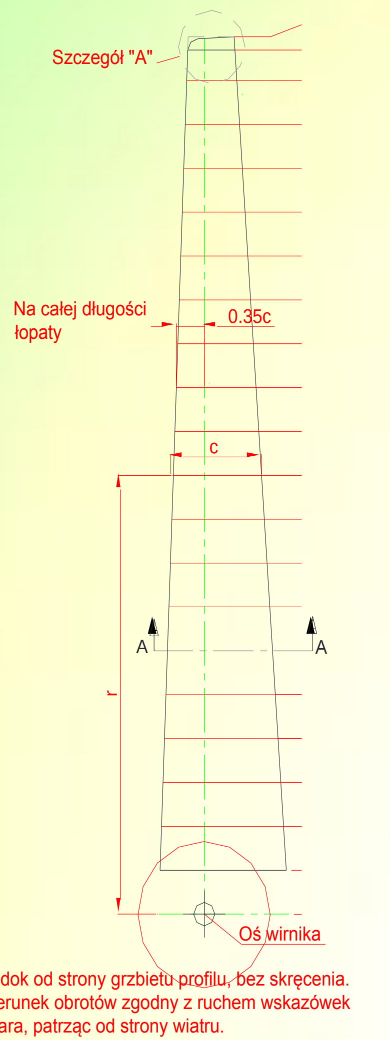
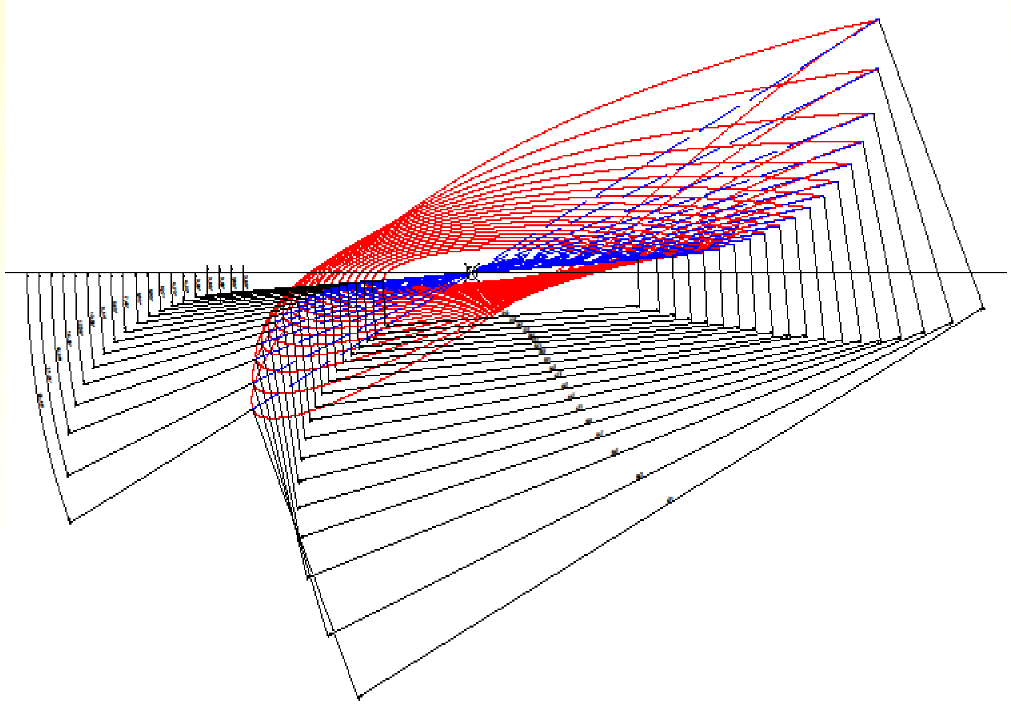


Nr	r [mm]	c [mm]	θ [stop.]
20	3750.0	217.0	3.60
20*	3700.0	222.3	3.60
19	3562.5	237.0	3.60
18	3375.0	257.0	3.60
17	3187.5	277.0	3.65
16	3000.0	297.0	3.90
15	2812.5	317.0	4.27
14	2625.0	337.0	4.73
13	2437.5	357.0	5.27
12	2250.0	377.0	5.90
11	2062.5	397.0	6.62
10	1875.0	417.0	7.45
9	1687.5	437.0	8.40
8	1500.0	457.0	9.51
7	1312.5	477.0	10.83
6	1125.0	497.0	12.39
5	937.5	517.0	14.35
4	750.0	537.0	16.98
3	562.5	557.0	21.04
2	375.0	577.0	25.48
1	187.5	597.0	--
0	--	--	--



Prototype of SWT's blade

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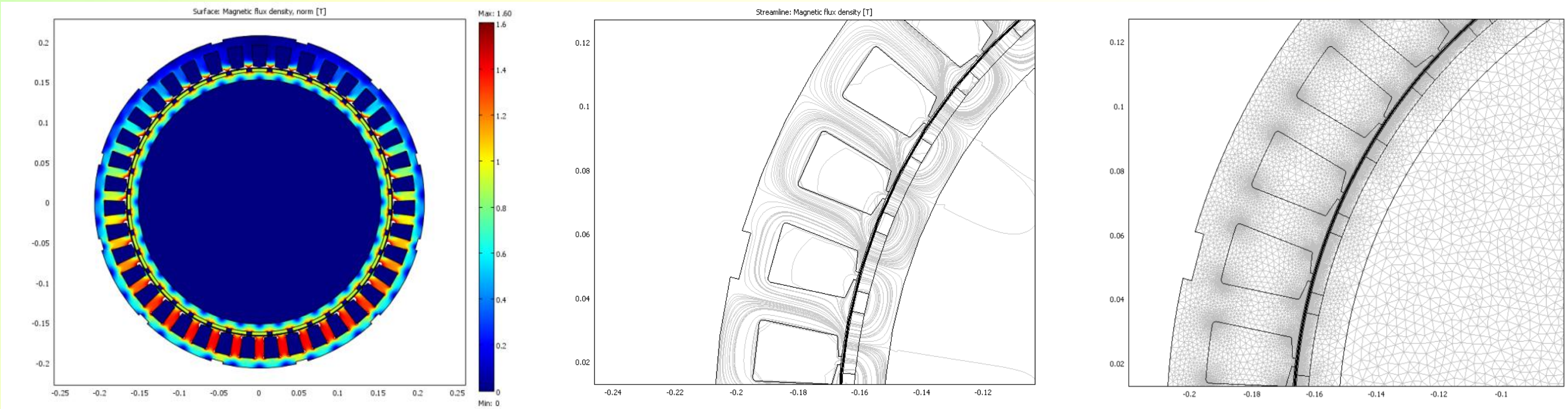
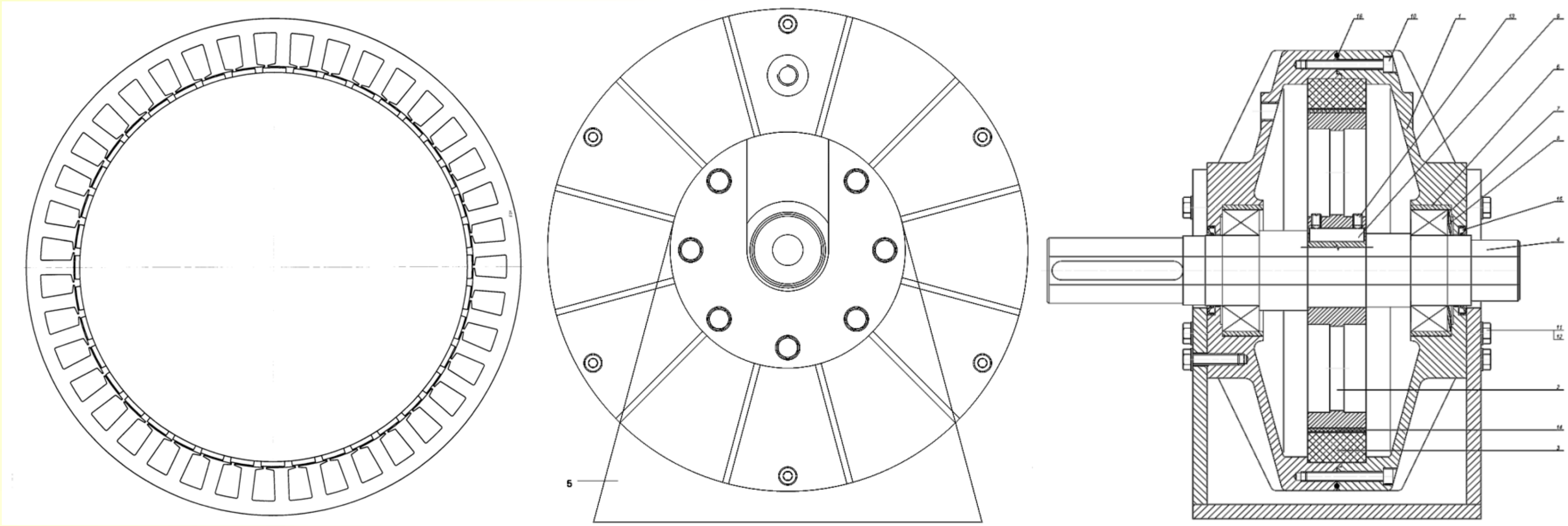
Small variable speed wind turbine with energy storage module





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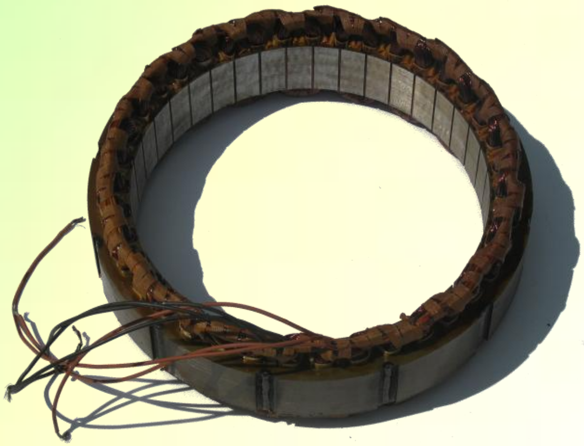

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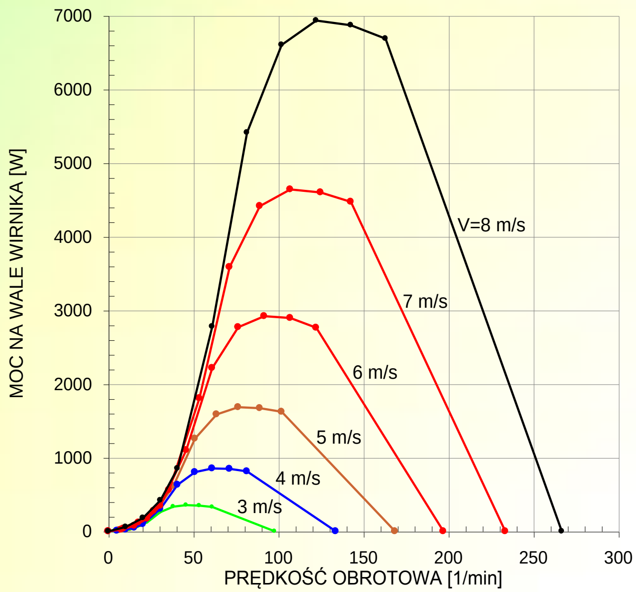
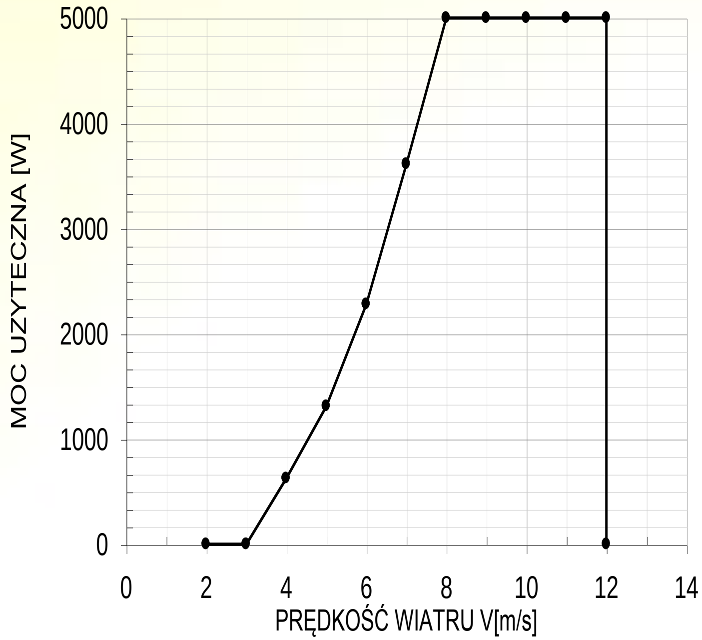
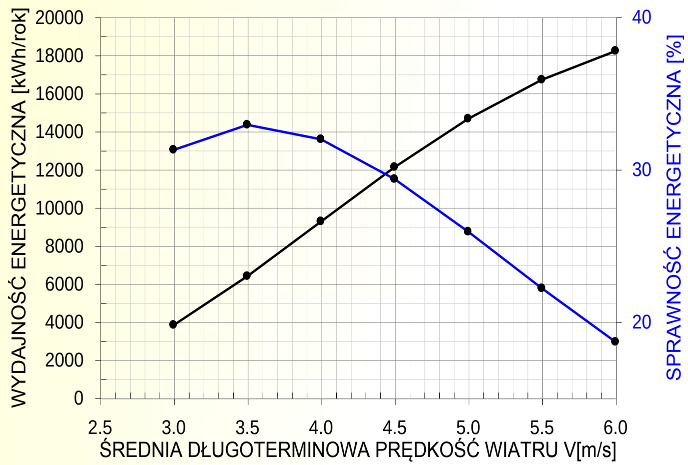


Power curve of WT



Energy productivity and eficiency



Influence of cogging and friction torques for WT eficiency

Marek Jasinski

Small variable speed wind turbine with energy storage module

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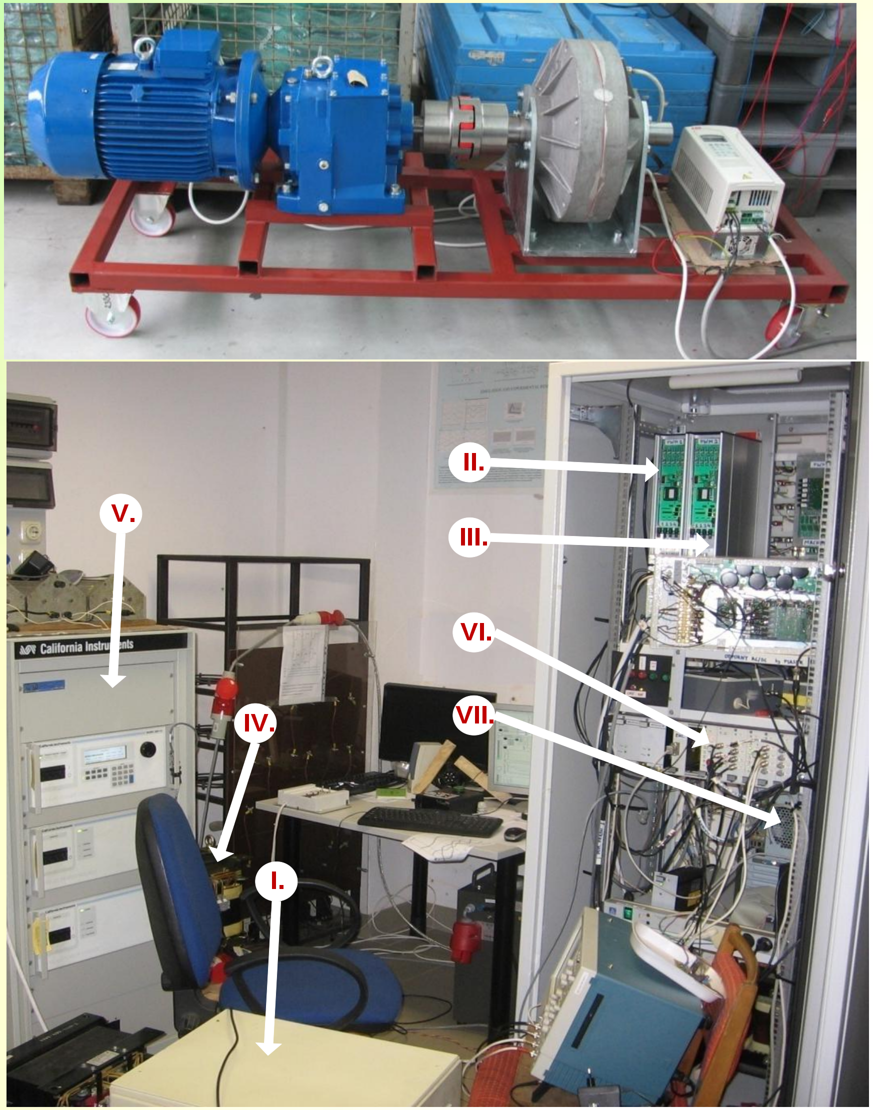
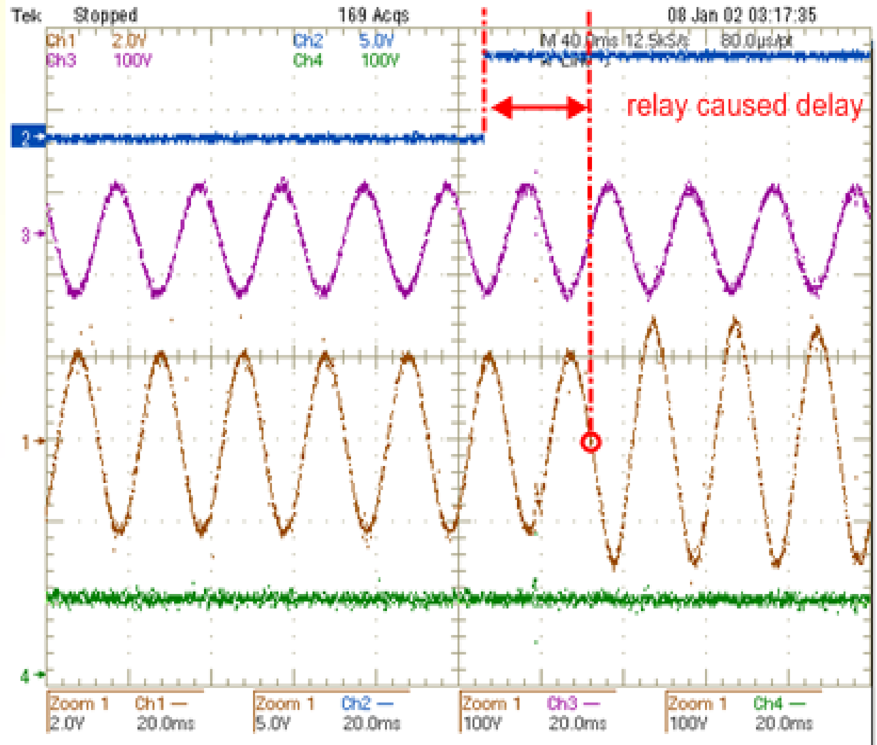
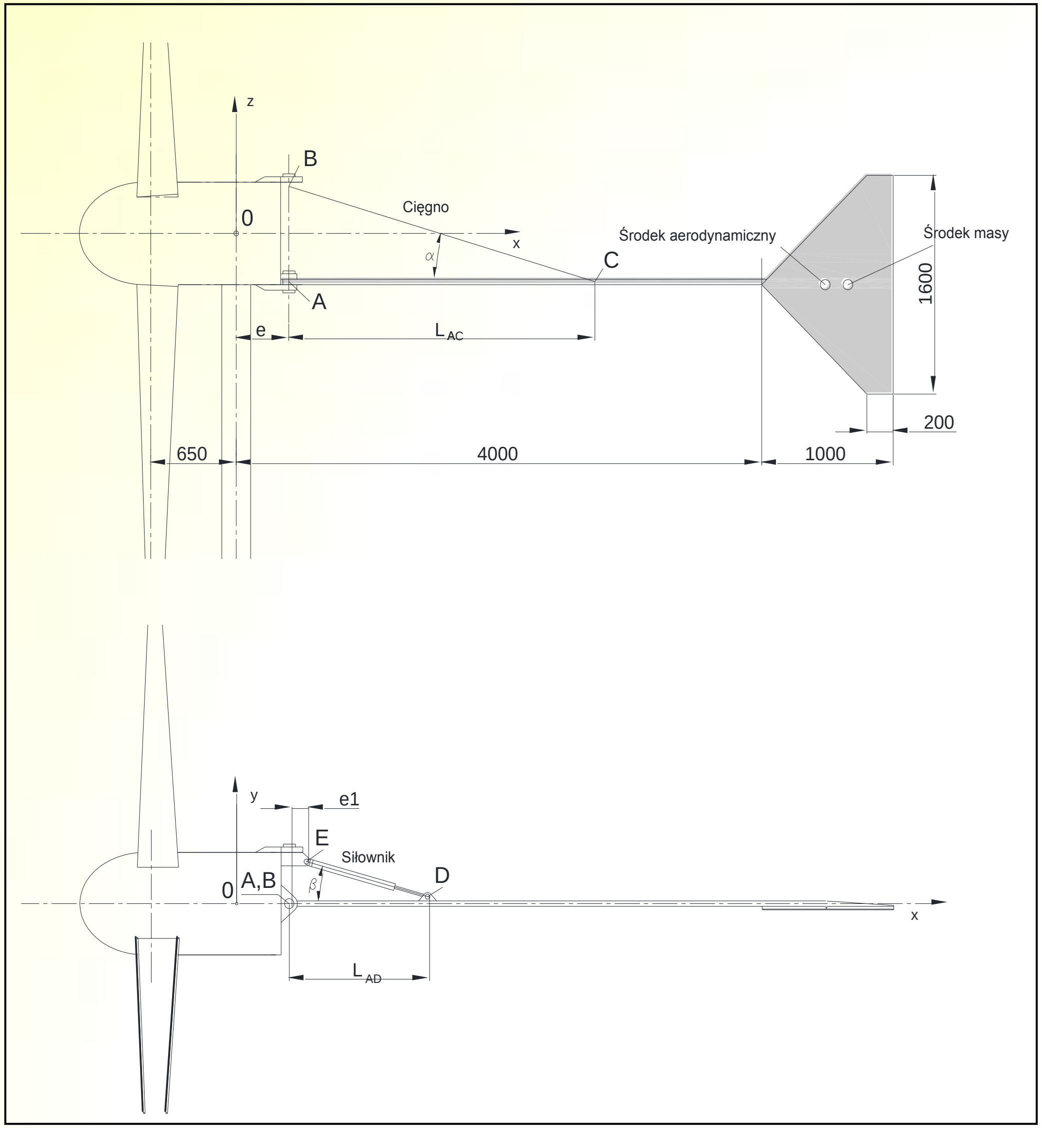


Lab setup



From the top: mode of operation, phase voltage u_{La}, phase current i_{La}, dc-link voltage U_{DC}

Small variable speed wind turbine with energy storage module



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Small variable speed wind turbine with energy storage module

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Investigation and development of simplified topology for three-level NPC AC/DC/AC converter for wind turbines

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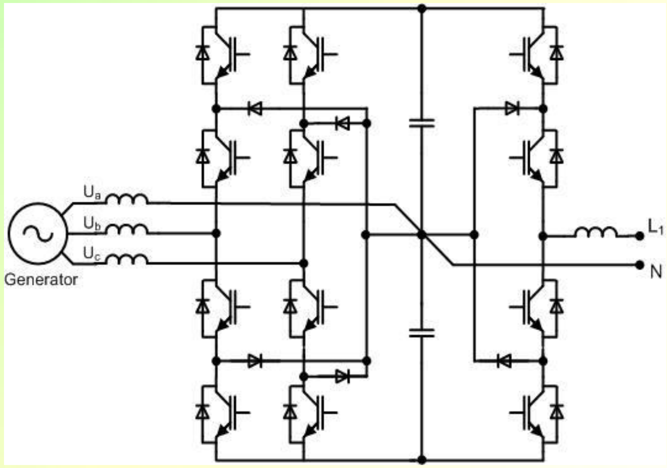
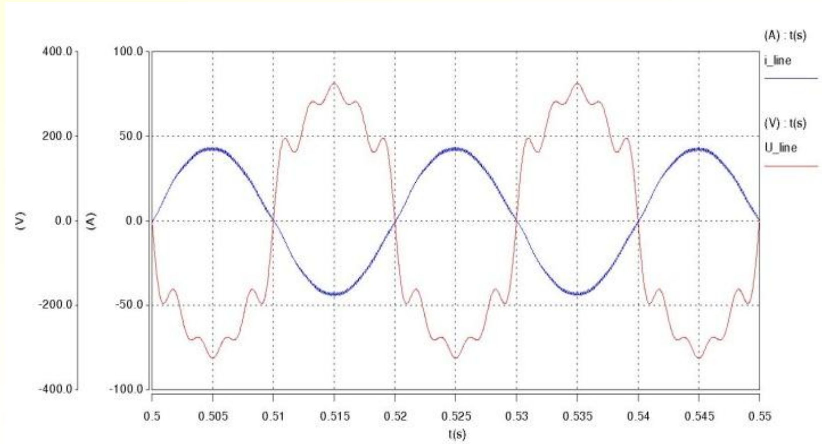
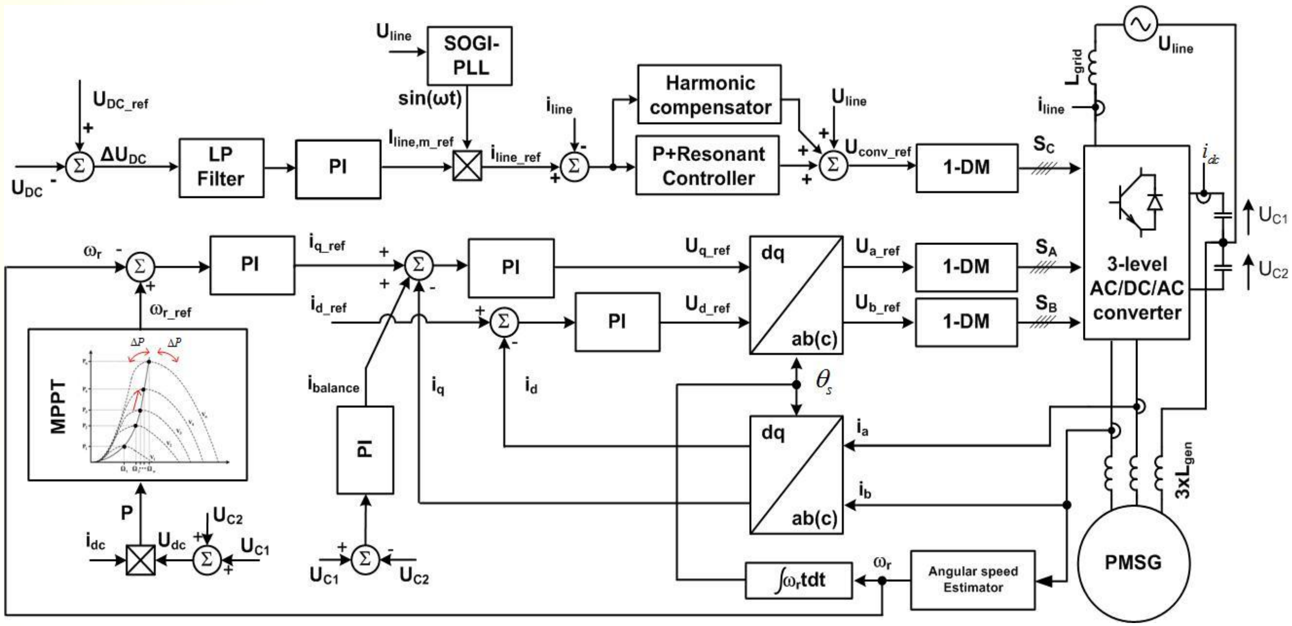
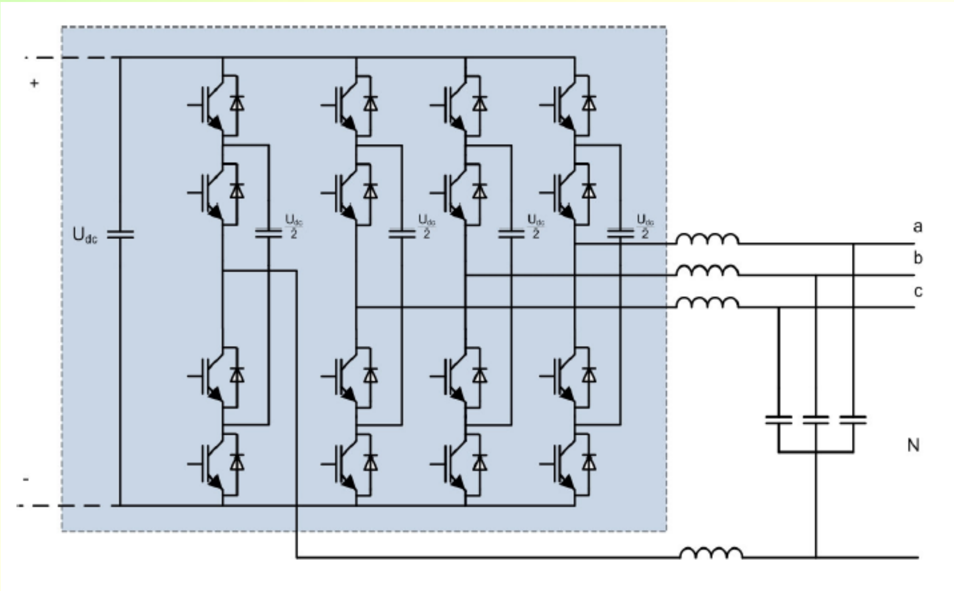


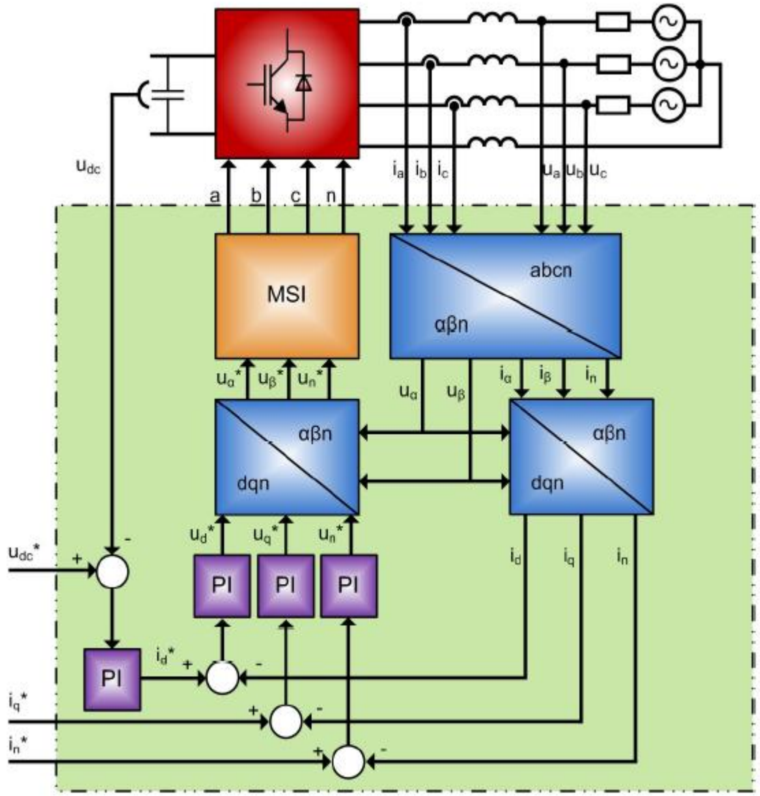




Marek Jasinski

Transformerless four-leg three-level converter for renewable energy systems





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Series of single-phase (2,3 and 5.5kW) high efficiency and transformerless DC/AC converters for PV panels

Industrial project

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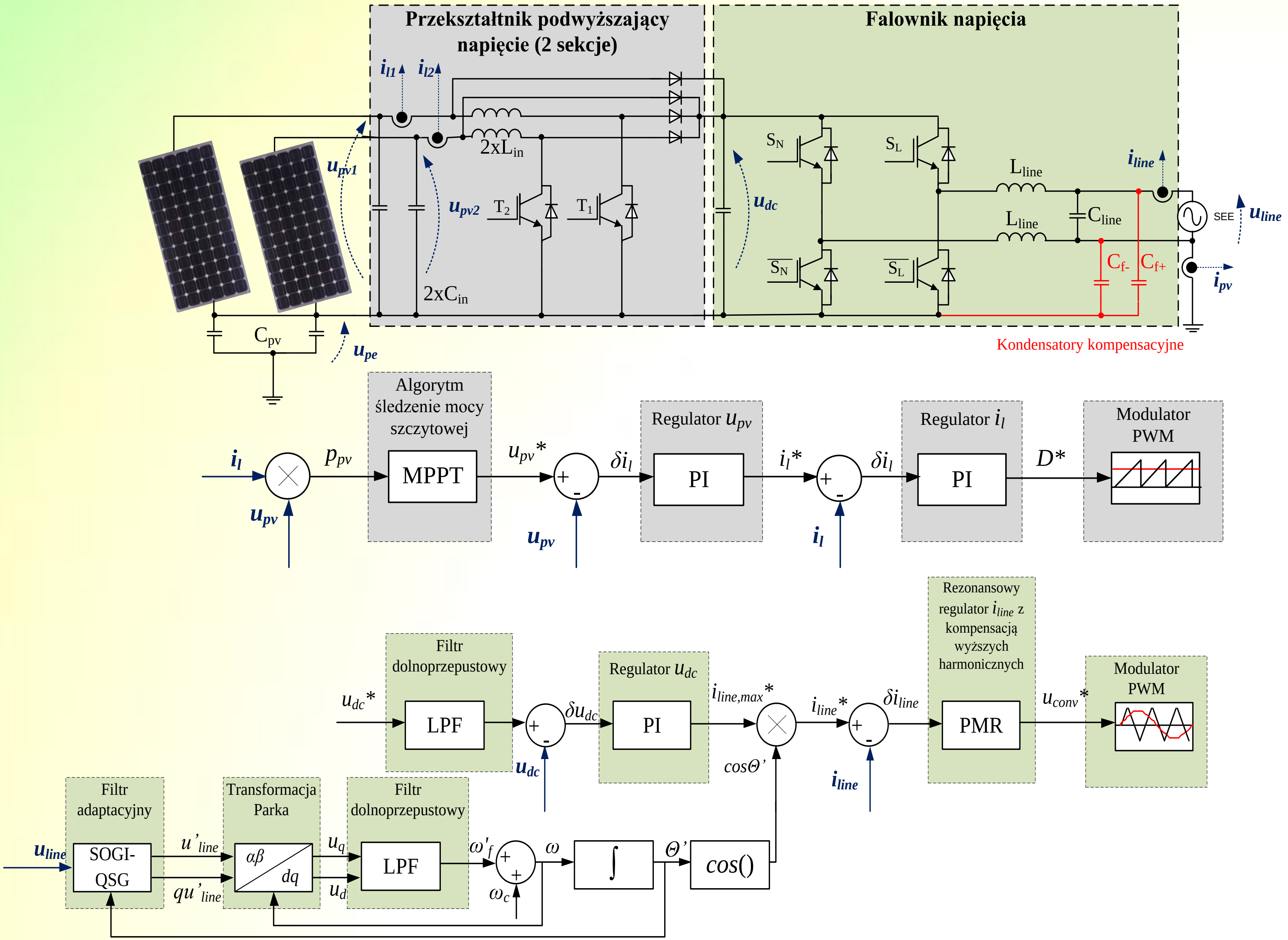

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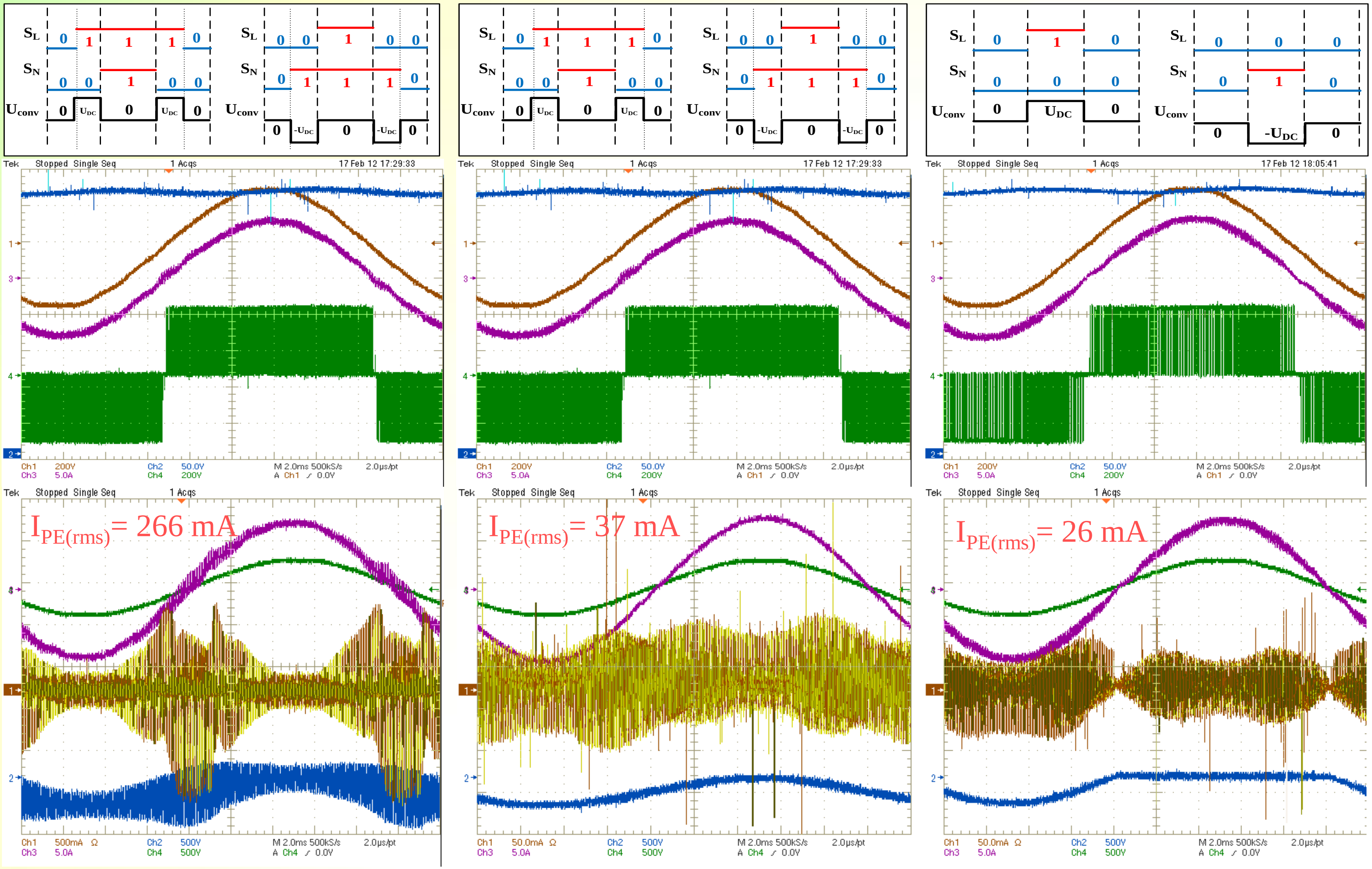
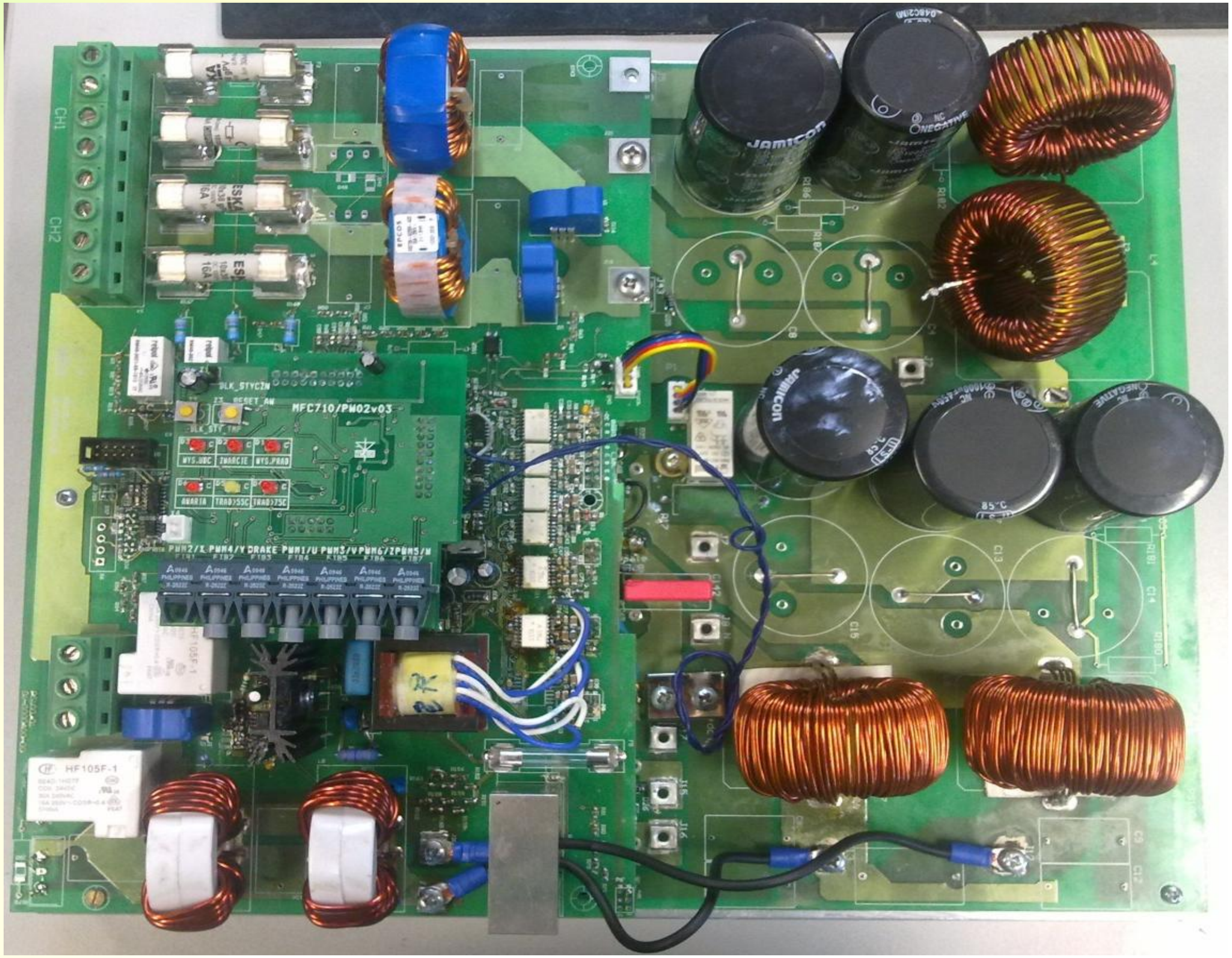
MODULACJA UNIPOLARNA **MODULACJA HYBRYDOWA**



Line voltage (green), line current (purple), leakage current (brown); (C_{pv}=13 nF, C_{f+}= C_{f-}=1 uF)

Twerd – **Series of high efficiency and transformerless DC/AC converters for PV panels** (**2, 3 i 5.5kW)**

Industrial project



Marek Jasinski

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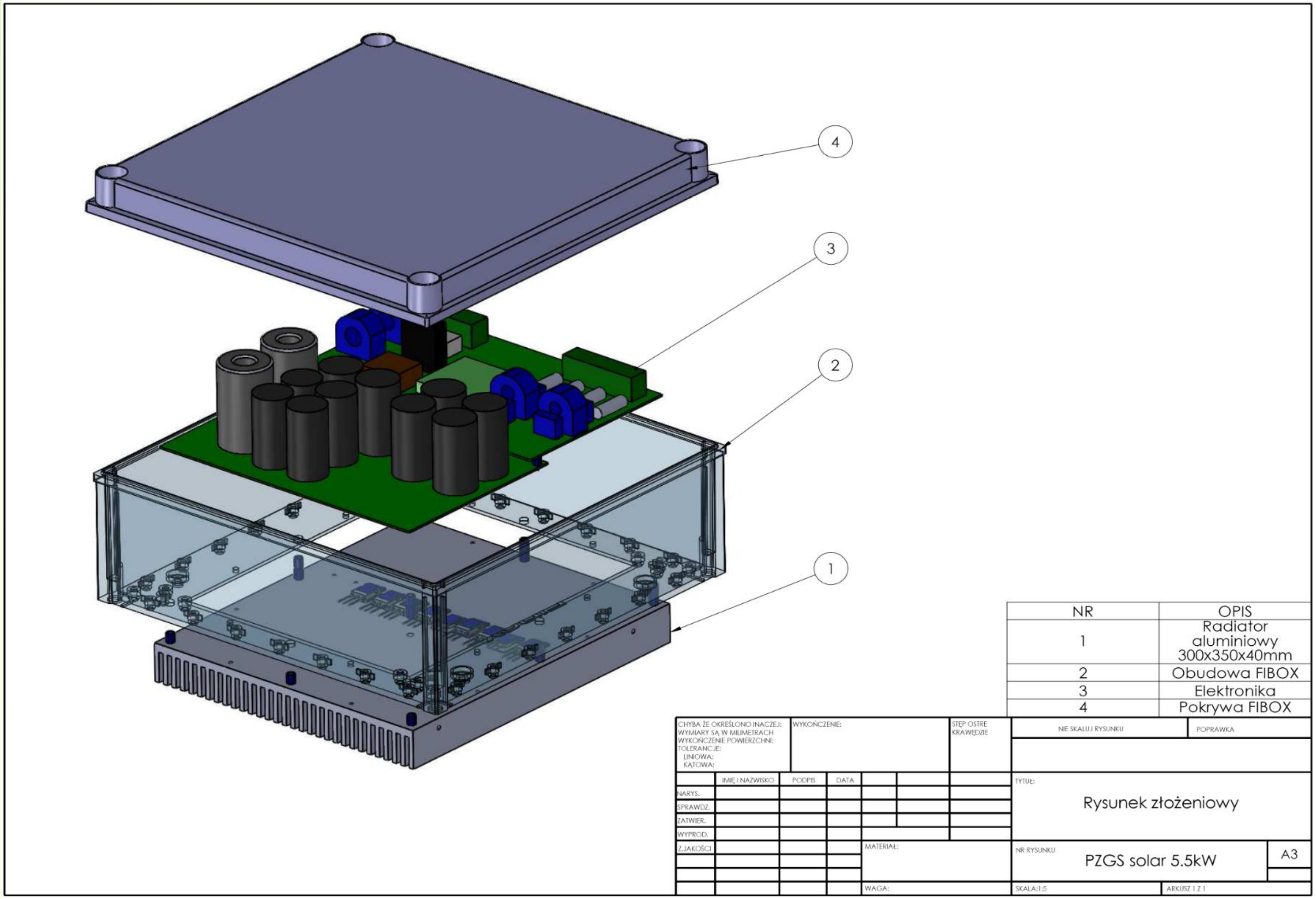
Industrial project



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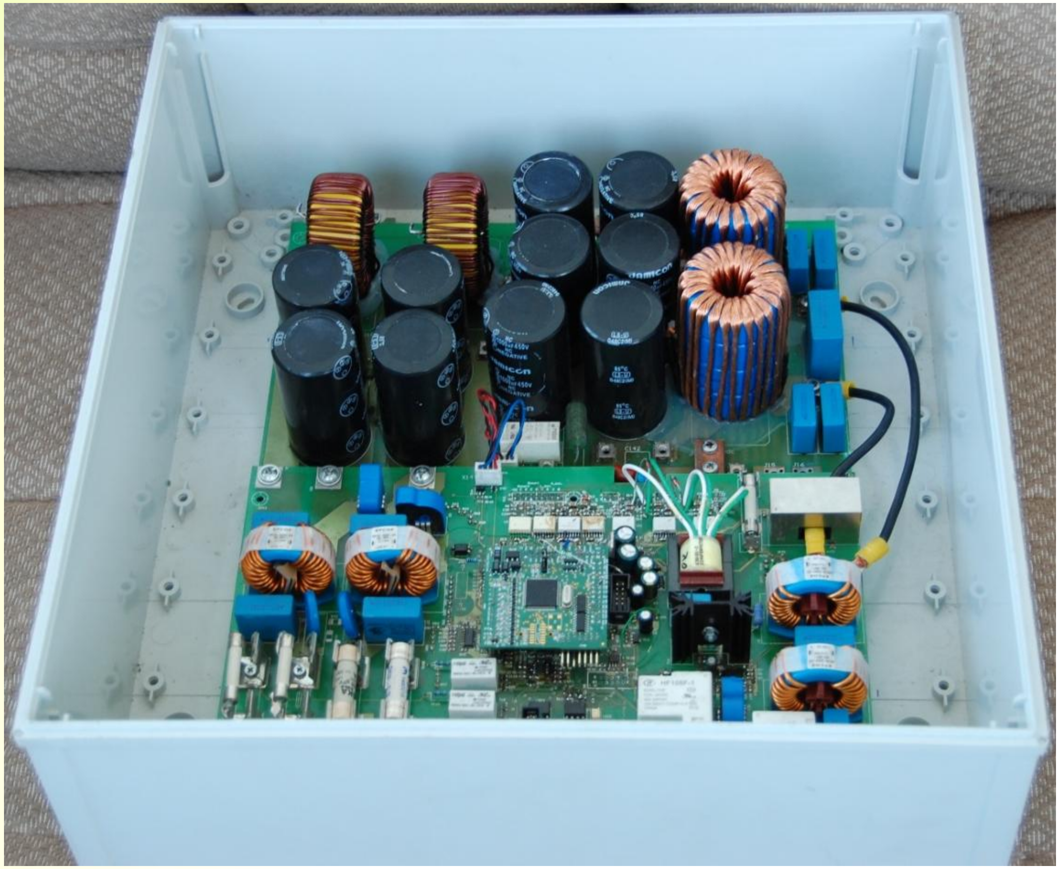
Mariusz Malinowski
Marek Jasinski

Twerd – **Series of high efficiency and transformerless DC/AC converters for PV panels** (**2, 3 i 5.5kW)**

Industrial project



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Wybrane zagadnienia w sterowaniu sprzęgów energoelektronicznych AC-DC-AC pomiędzy odnawialnymi źródłami energii a siecią elektroenergetyczną

Marek Jasiński

http://www.pw.edu.pl
http://www.isep.pw.edu.pl
http://www.isep.pw.edu.pl/ICG

Zielona Góra, Polska, the 20-th of September 2013

Elaboration of three-phase AC/DC converter (series 5 - 400 kVA) resistant for different grid disturbances – Green Converter

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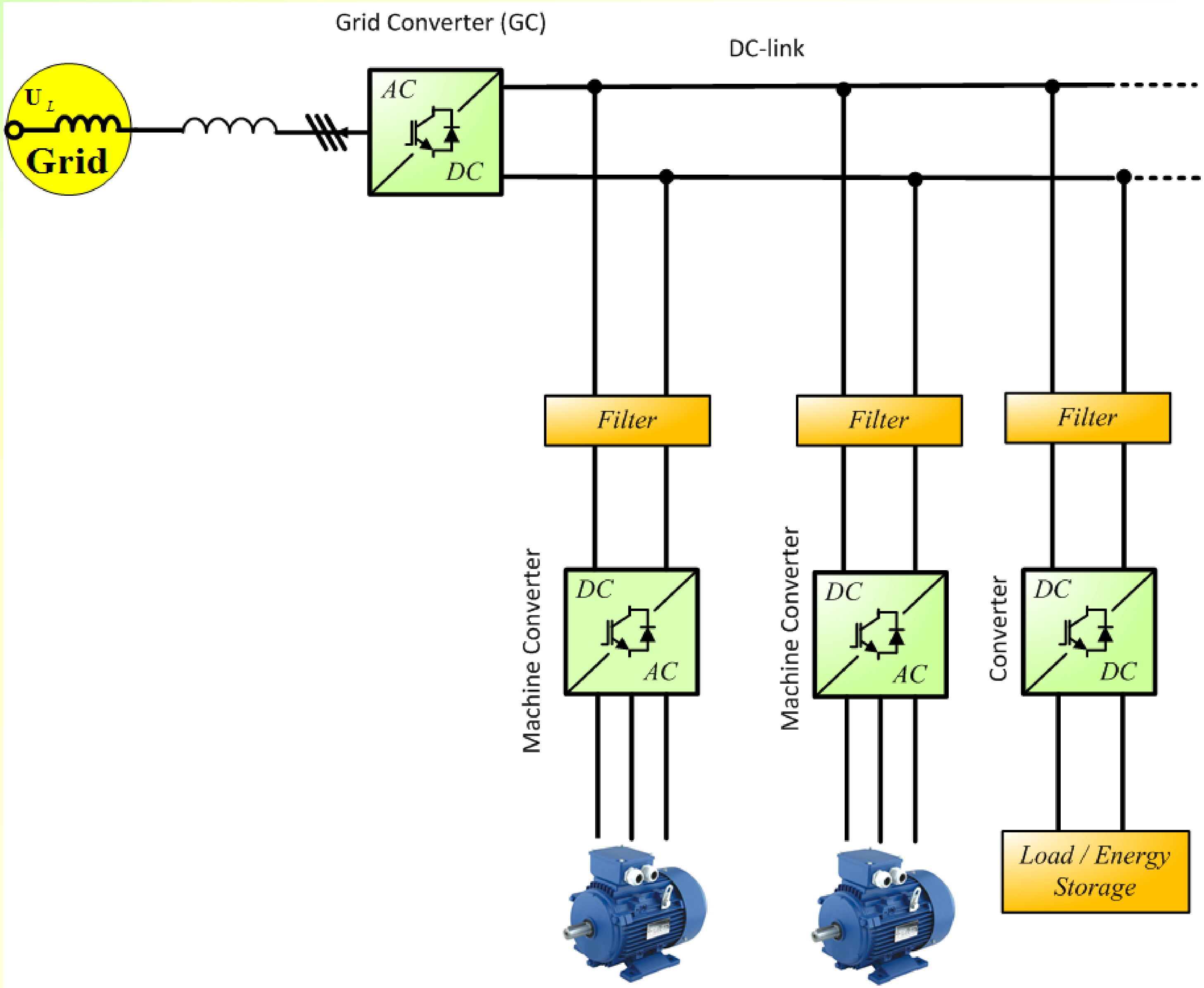

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Green Converter – Control Block Scheme

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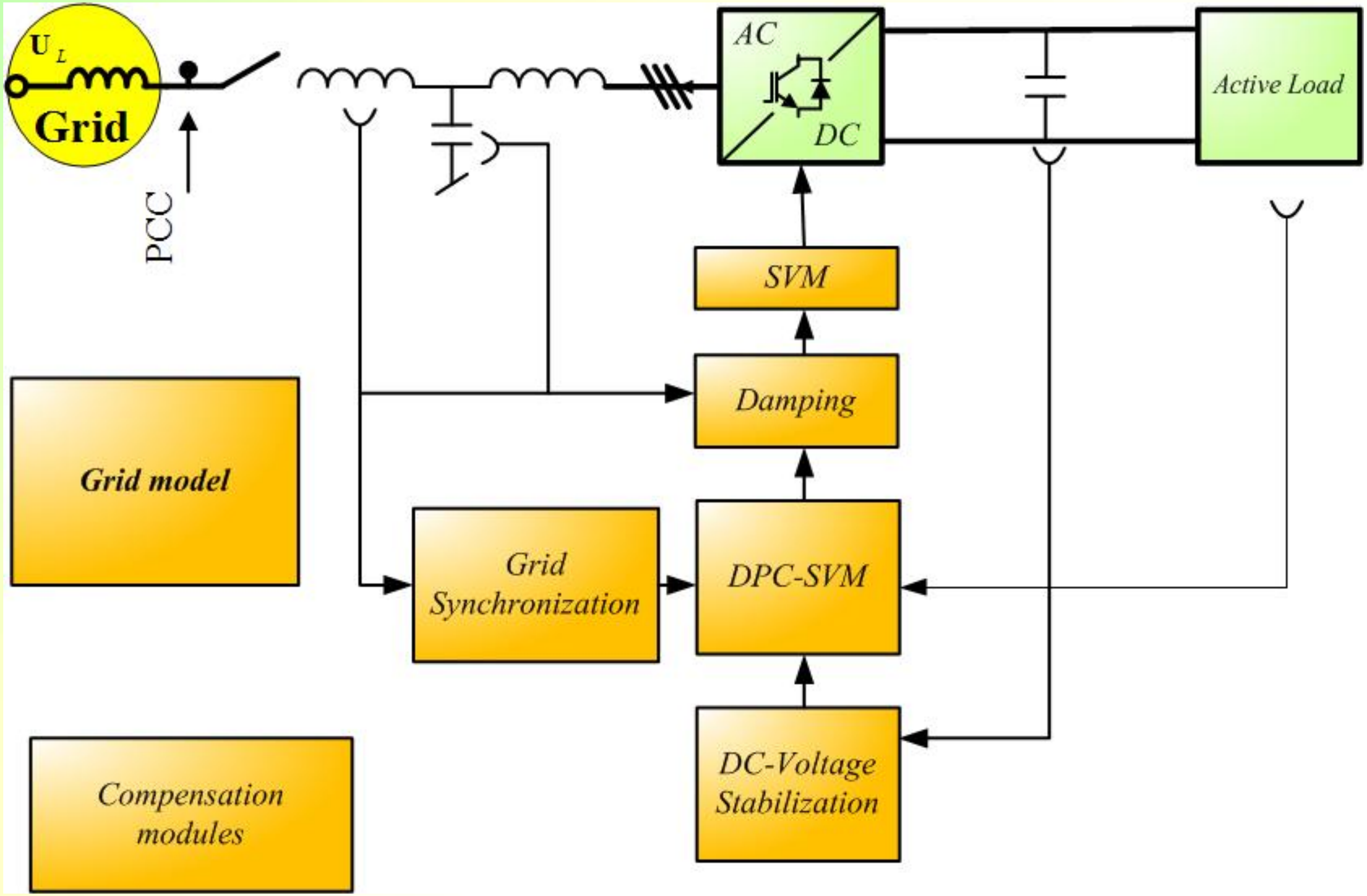

Power modularity of AC-DC converter

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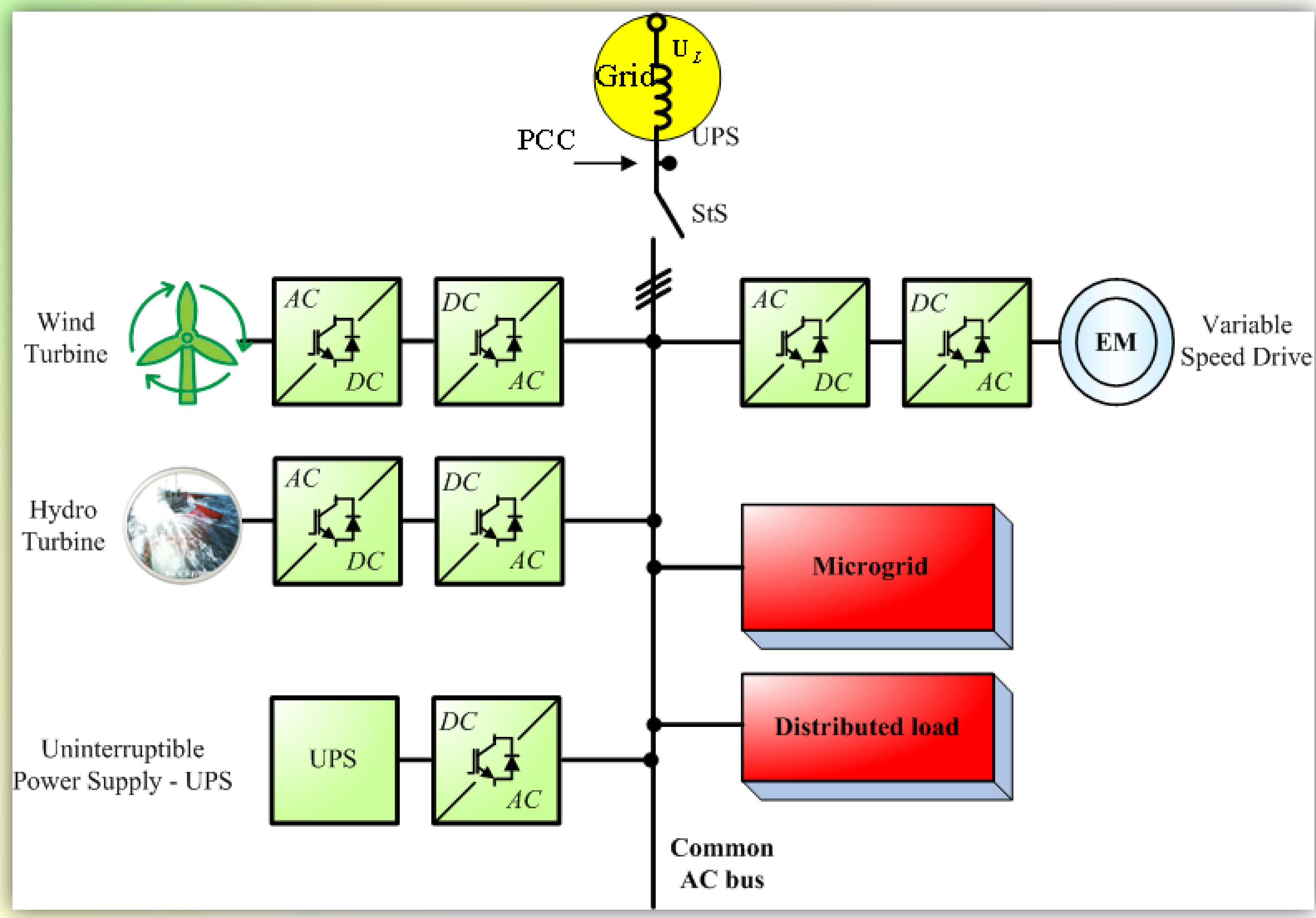
AC-DC Converter possible applications



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Some control methods of an AC-DC-AC

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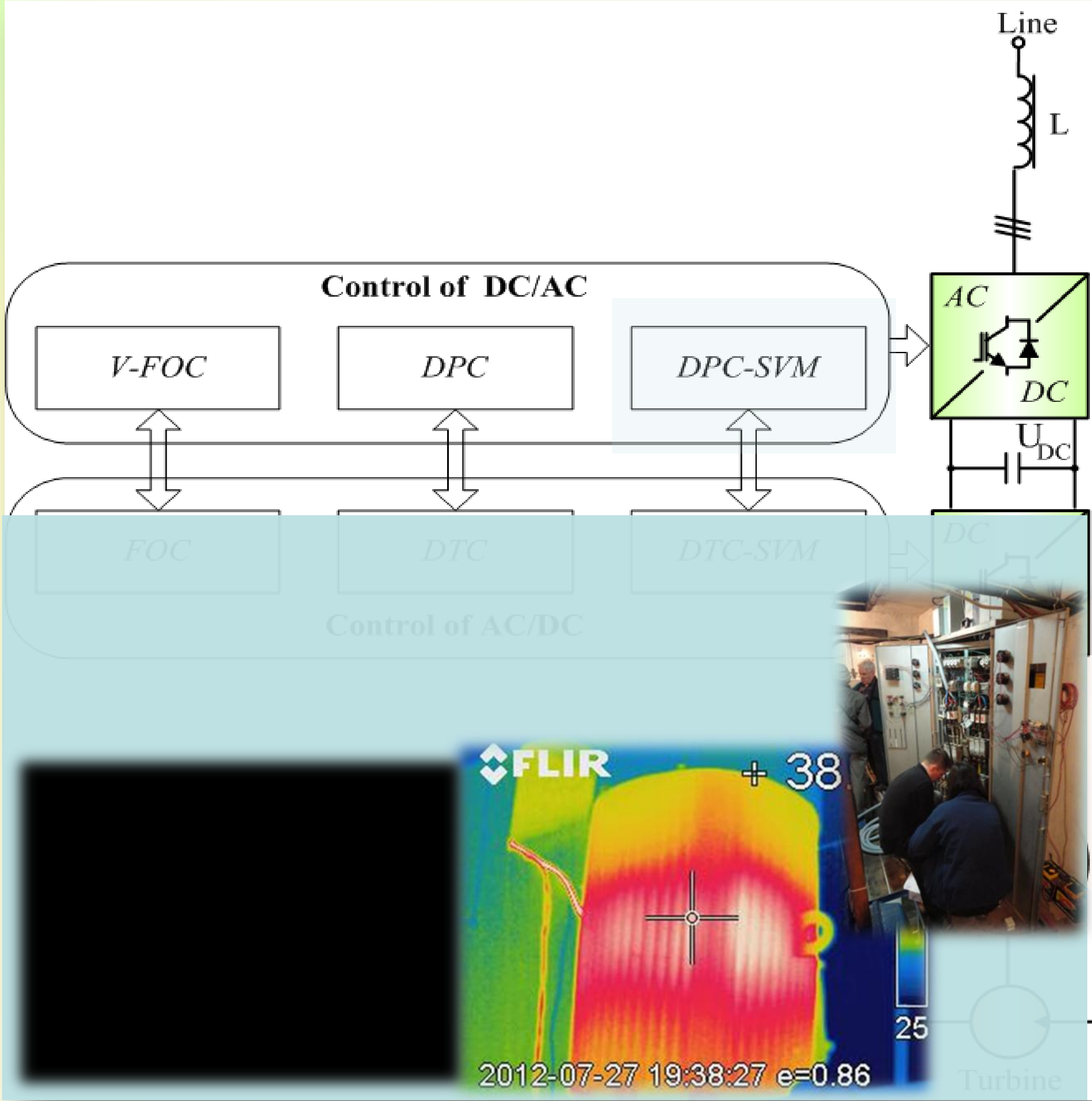

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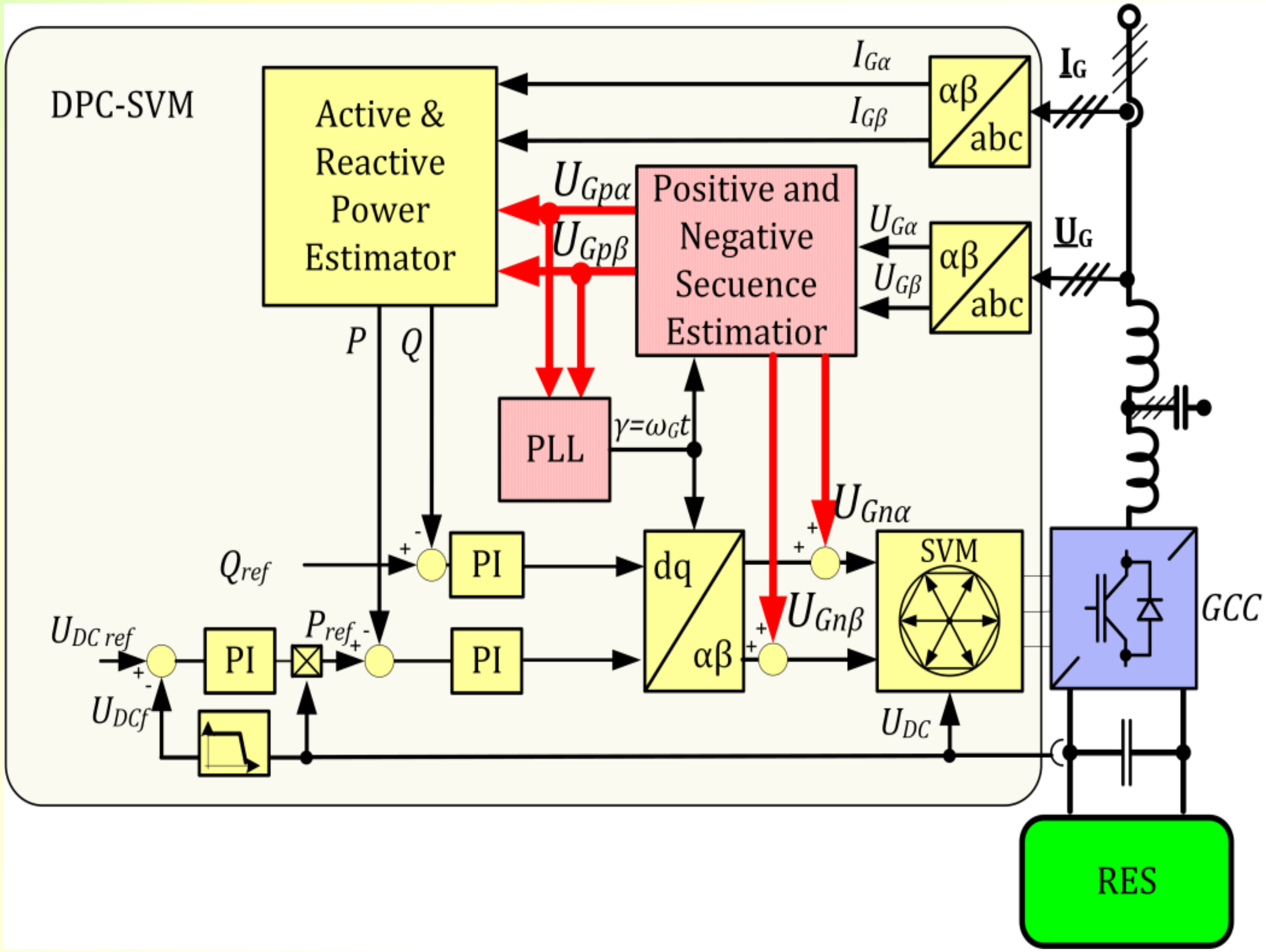
Green Converter - Control



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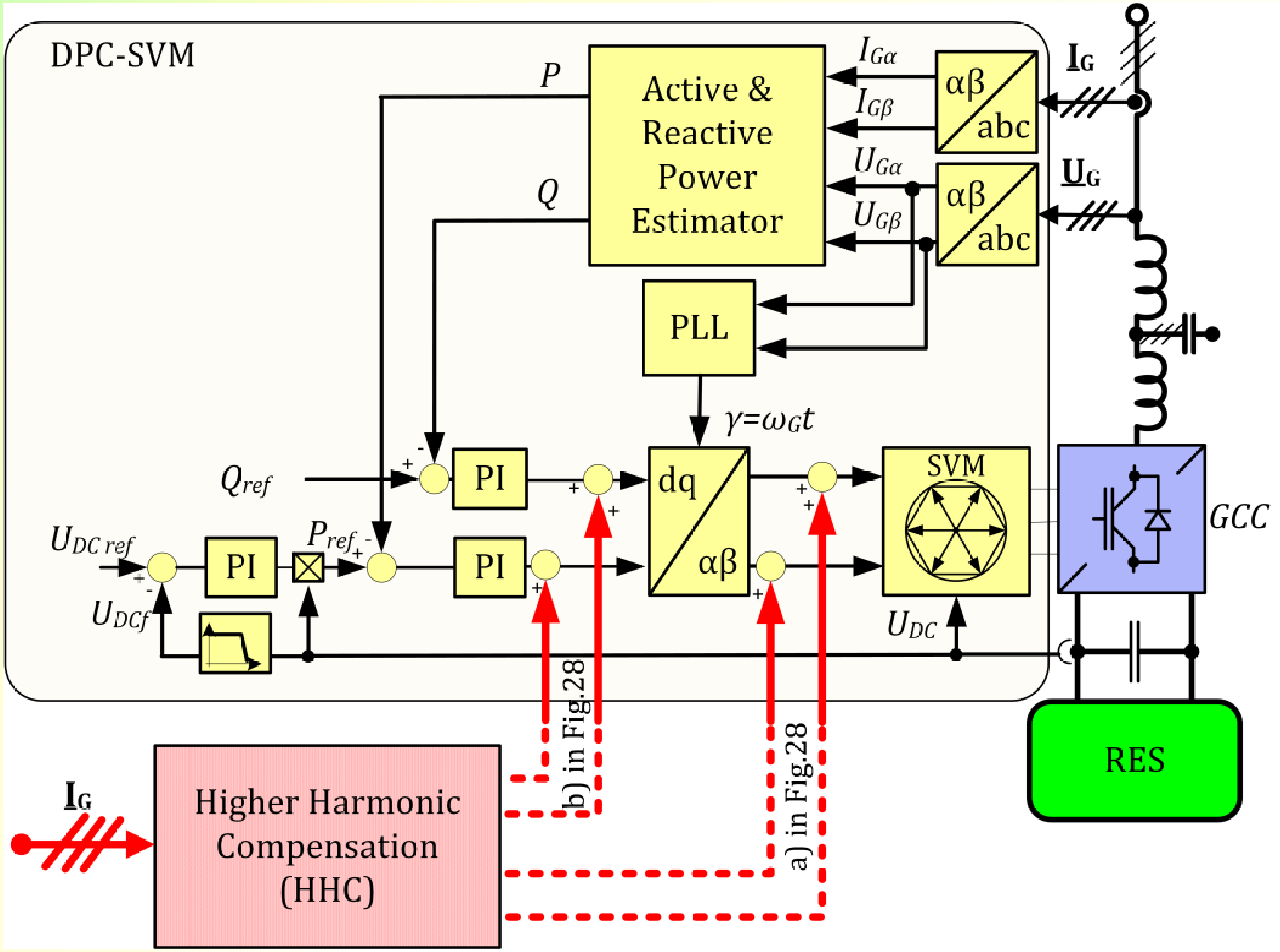
Green Converter - Control



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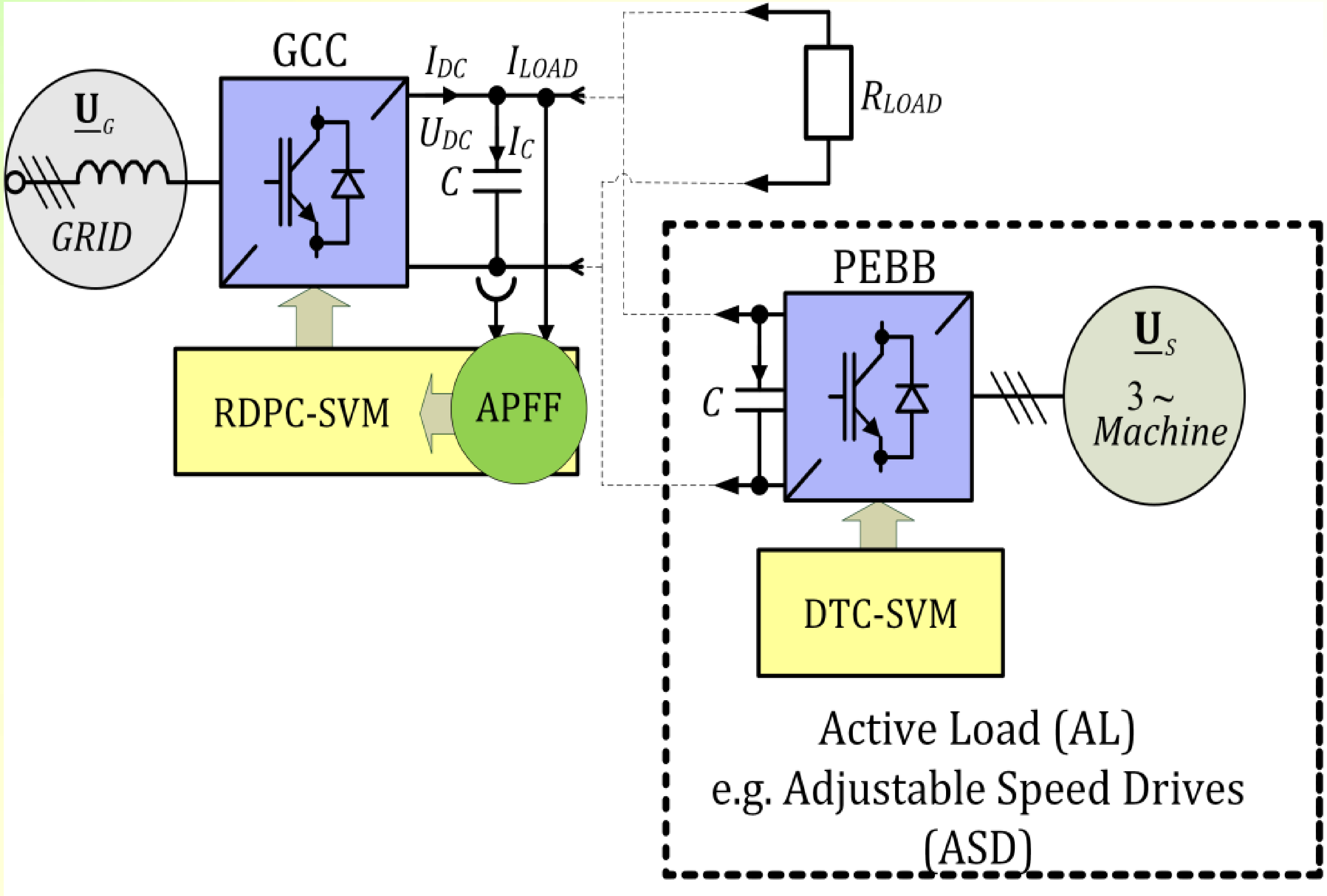
Green Converter - Control



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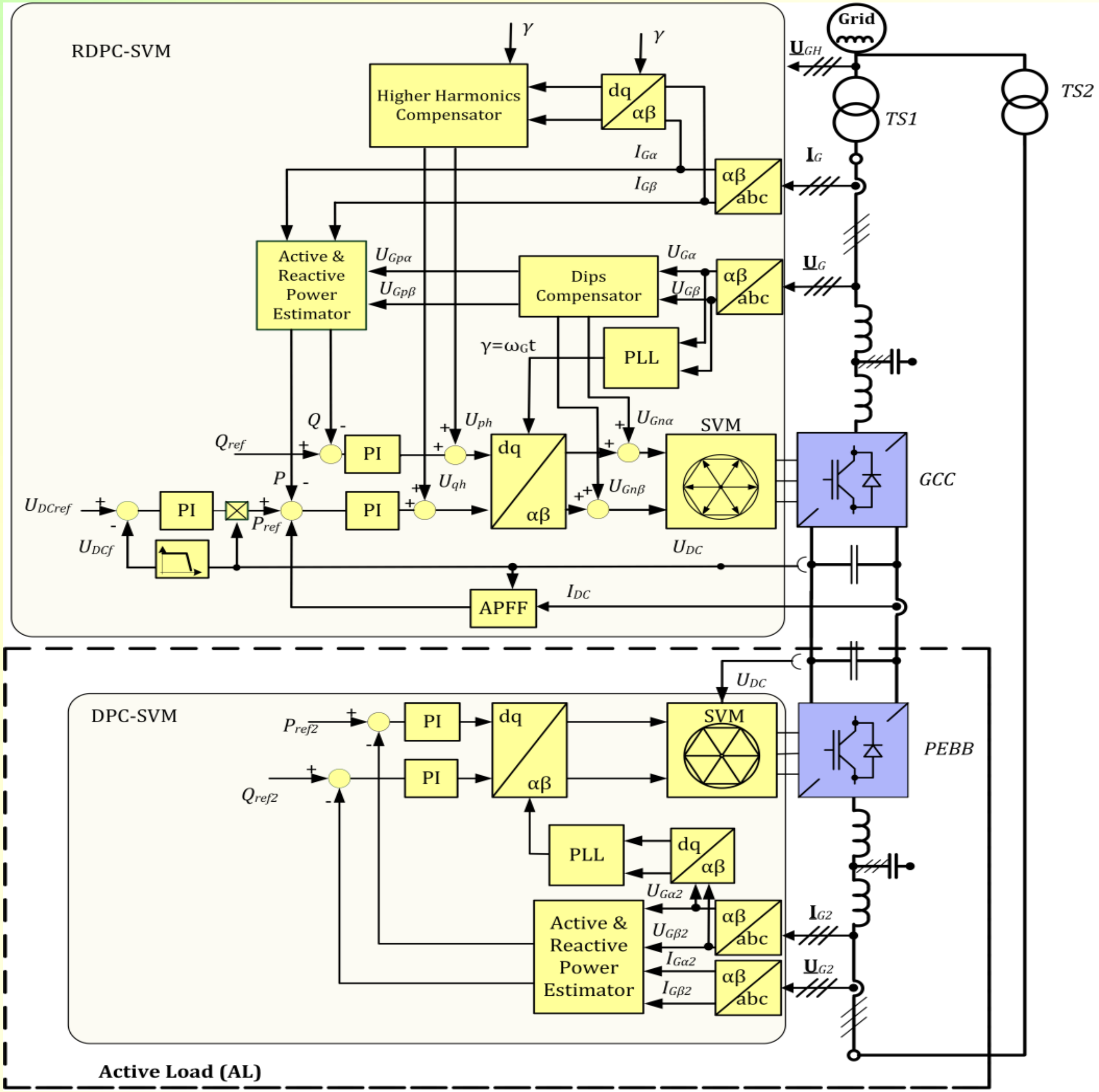
Green Converter - Control



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Simulation results

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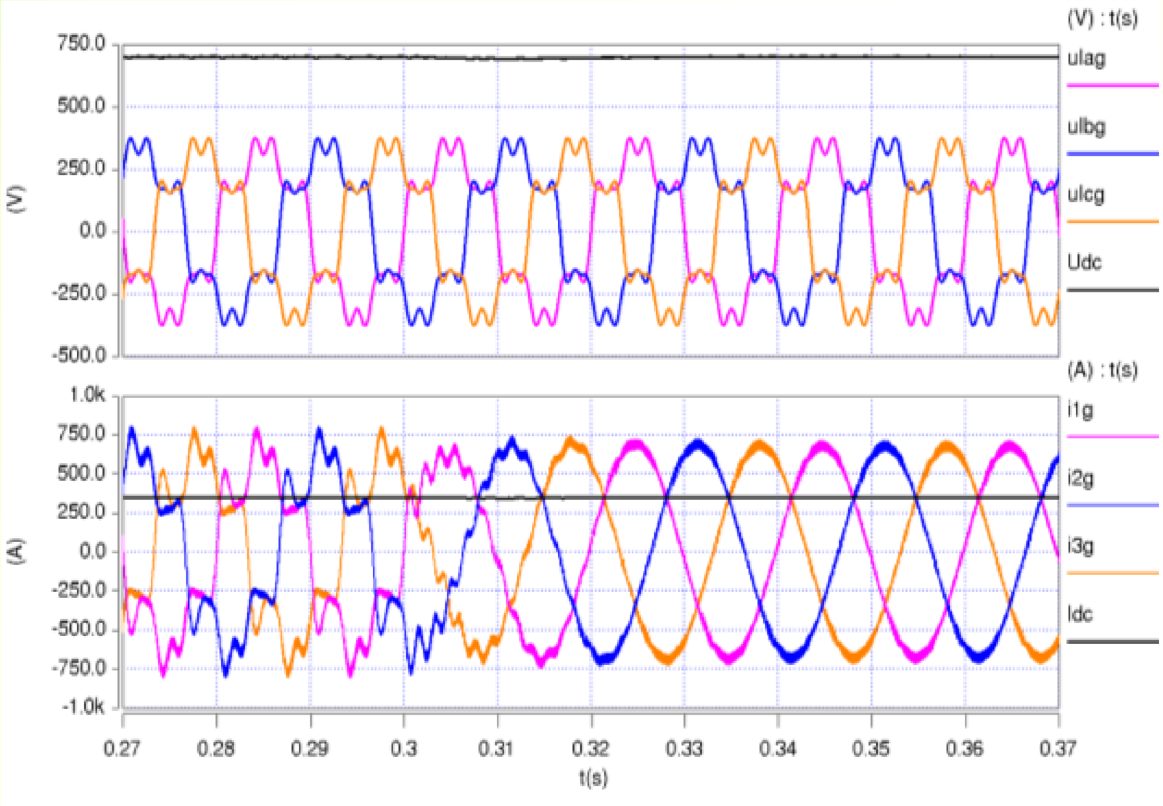

Start of the Harmonic Compensator. From the top: DC-link voltage, grid voltages, grid currents, DC-link current.

Start of the HC operation with 20% of 5th harmonic, 15% of 7th harmonic and 10% of 11th harmonic distortion in grid voltage is presented. The harmonics compensation was switched on in time t(s)= 0.3s.

Simulation results

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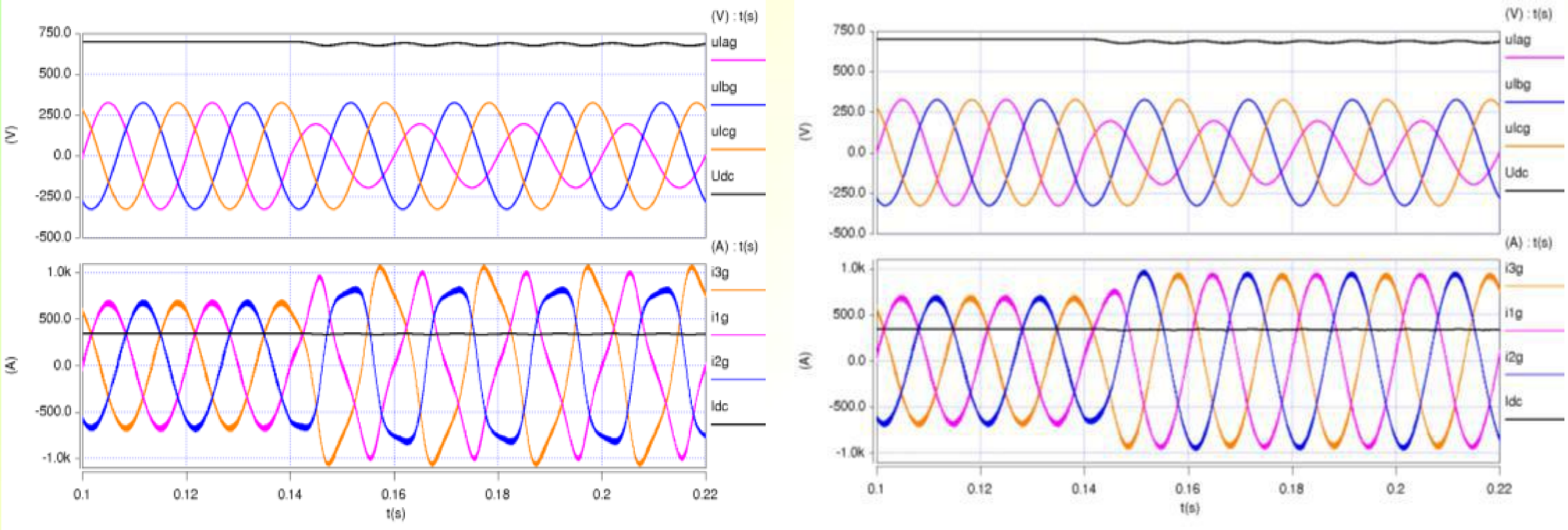

(a) (b)

60% Voltage dip in Phase A (a) without dips compensation and (b) with dips compensation in 400kVA rated power system. From the top DC-link voltage, grid voltages, grid currents and DC-link current.

Simulation results

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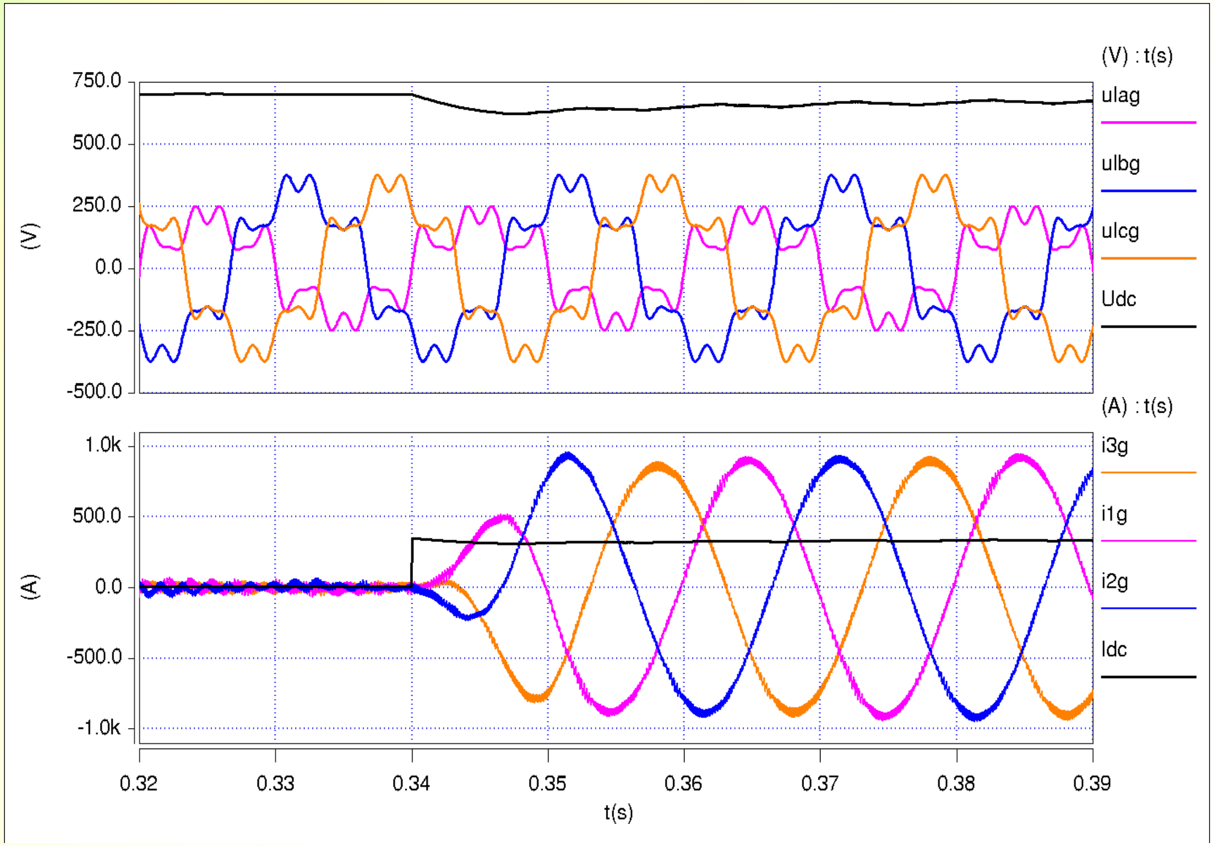

Step change of the load with 60% Voltage dip in Phase A and higher harmonics distortion (20% of 5th harmonic, 15% of 7th harmonic and 10% of 11th harmonic distortion). From the top DC-link voltage, grid voltages, grid currents and DC-link current.

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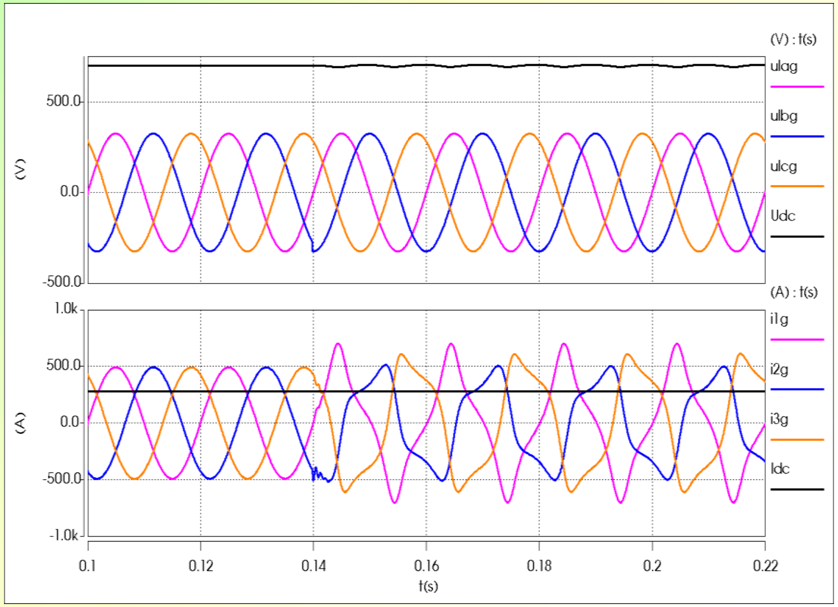
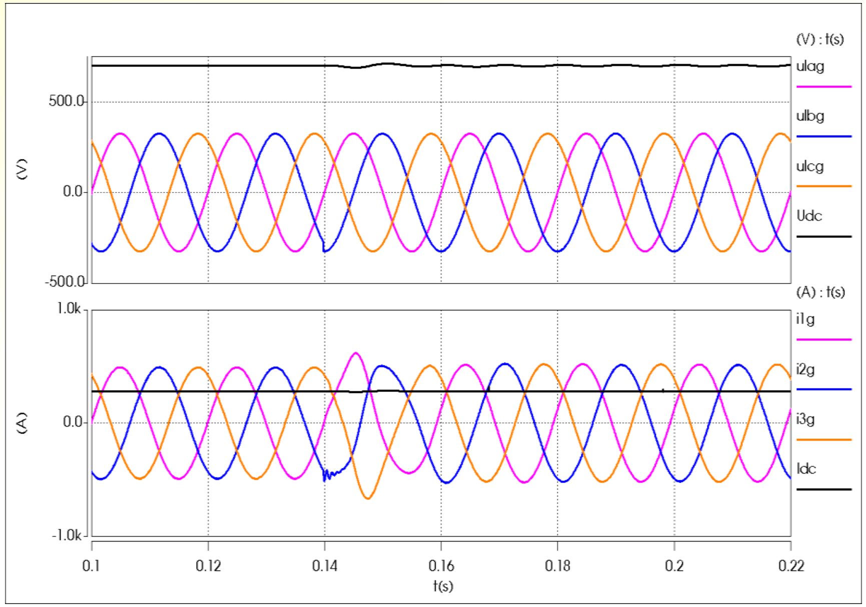
Simulation results



(a)



(b)

Single phase shift from 120 degree to 90 degree in Phase B; (a) without compensation and (b) with dips compensation in 400kVA rated power system. From the top DC-link voltage, grid voltages, grid currents and DC-link current.

5-15kVA Experimental platform

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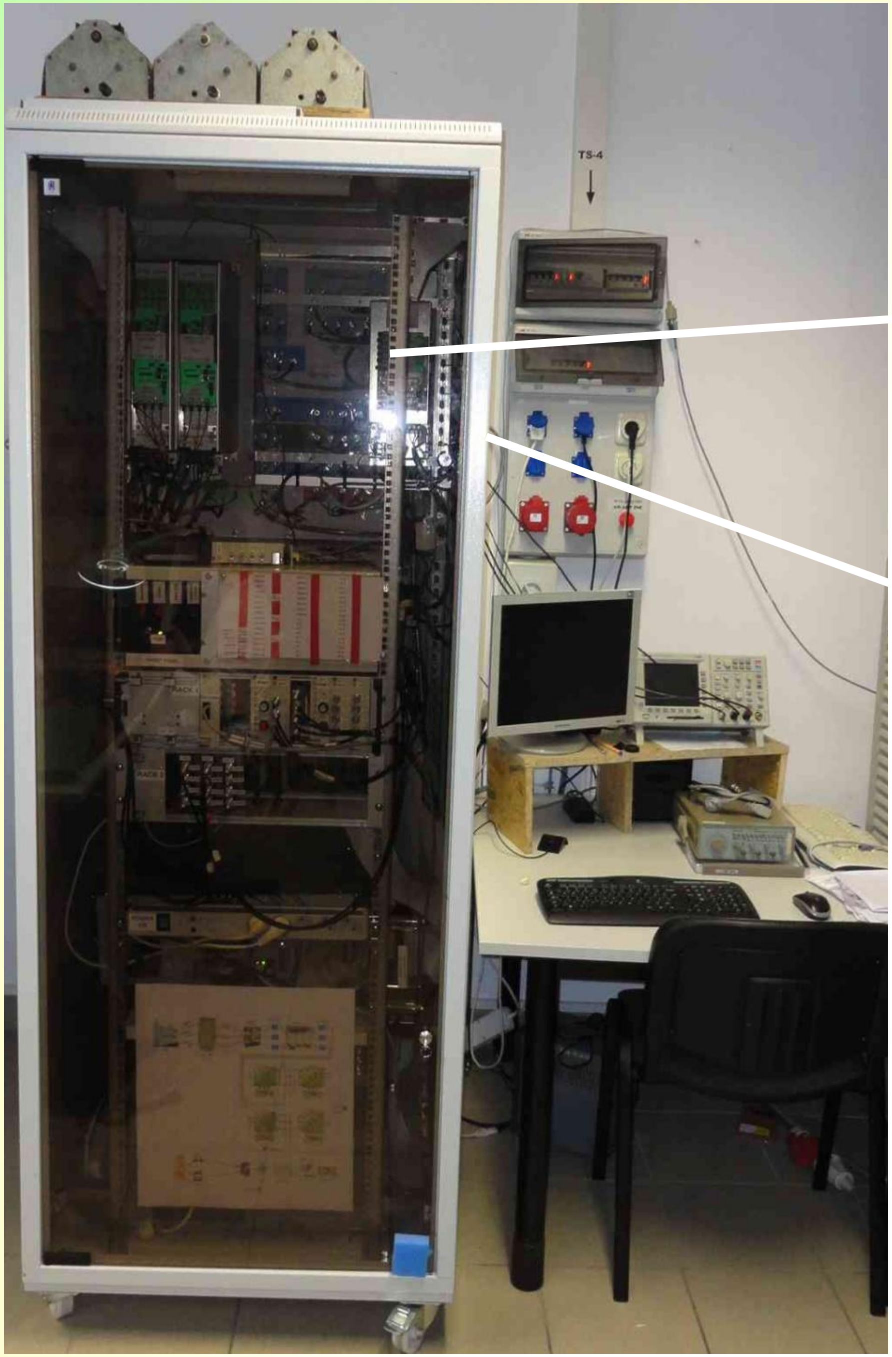

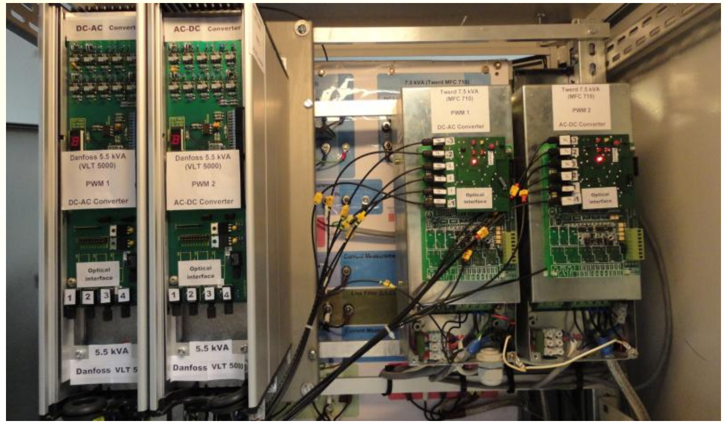

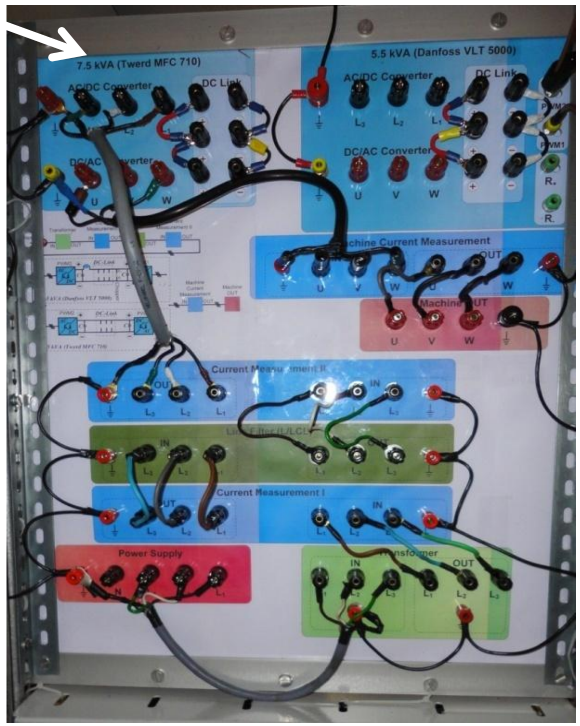

55kVA Experimental platform

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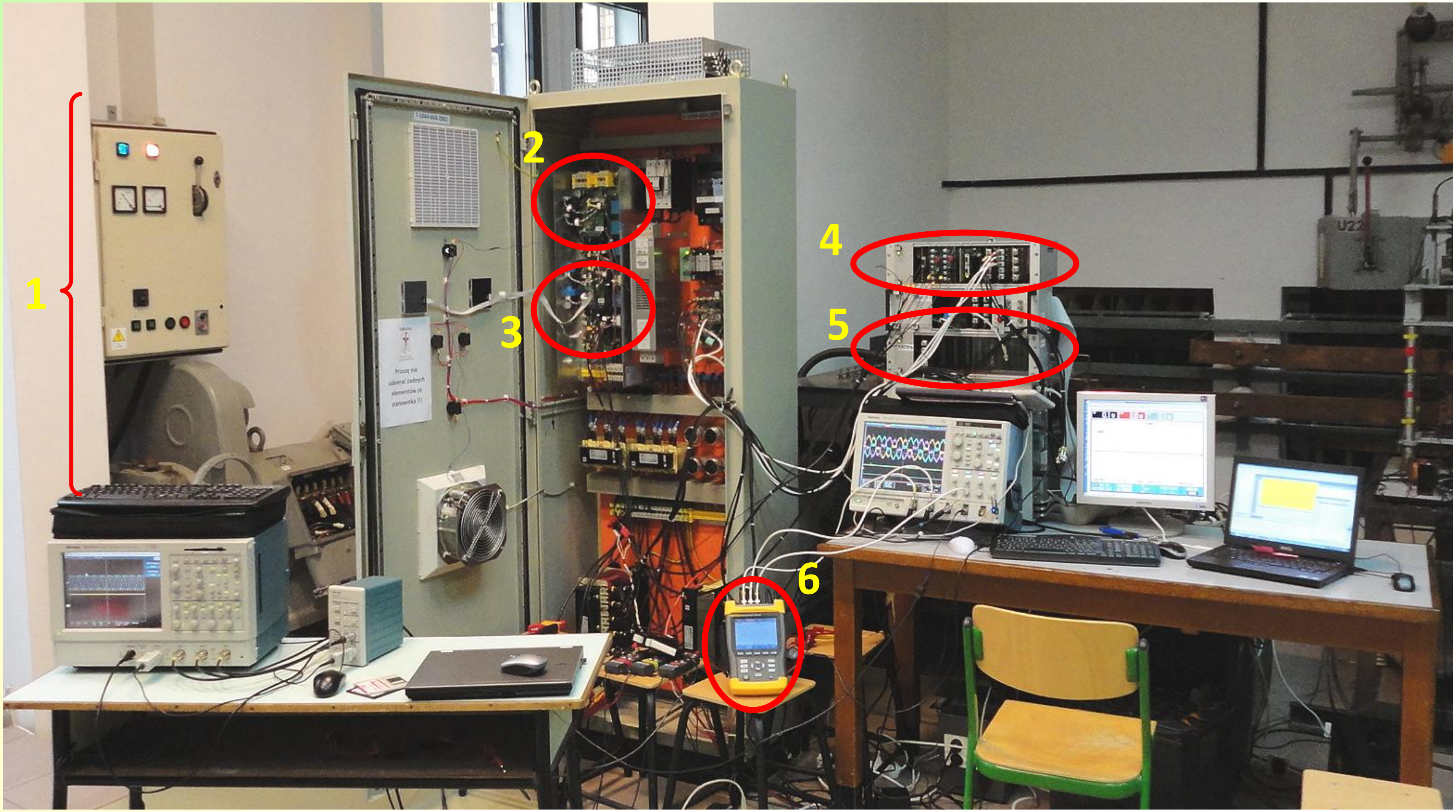

1. *Power supply with autotransformer* ***2.*** *AC-DC converter (Grid Convertr),* ***3.*** *DC-AC converter (Personal Convertr),* ***4.*** *Control platform - TMS 28335,* ***5.*** *Control platform - dSpace 1103,* ***6.*** *Power Quality Analyzer- Fluke.*

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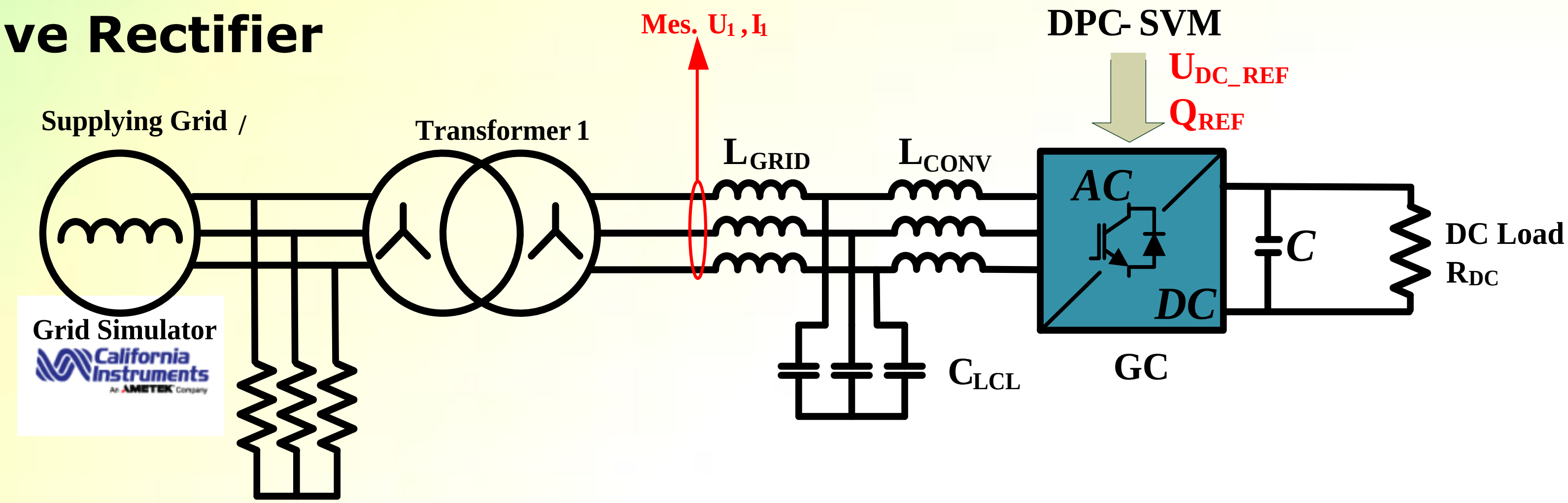
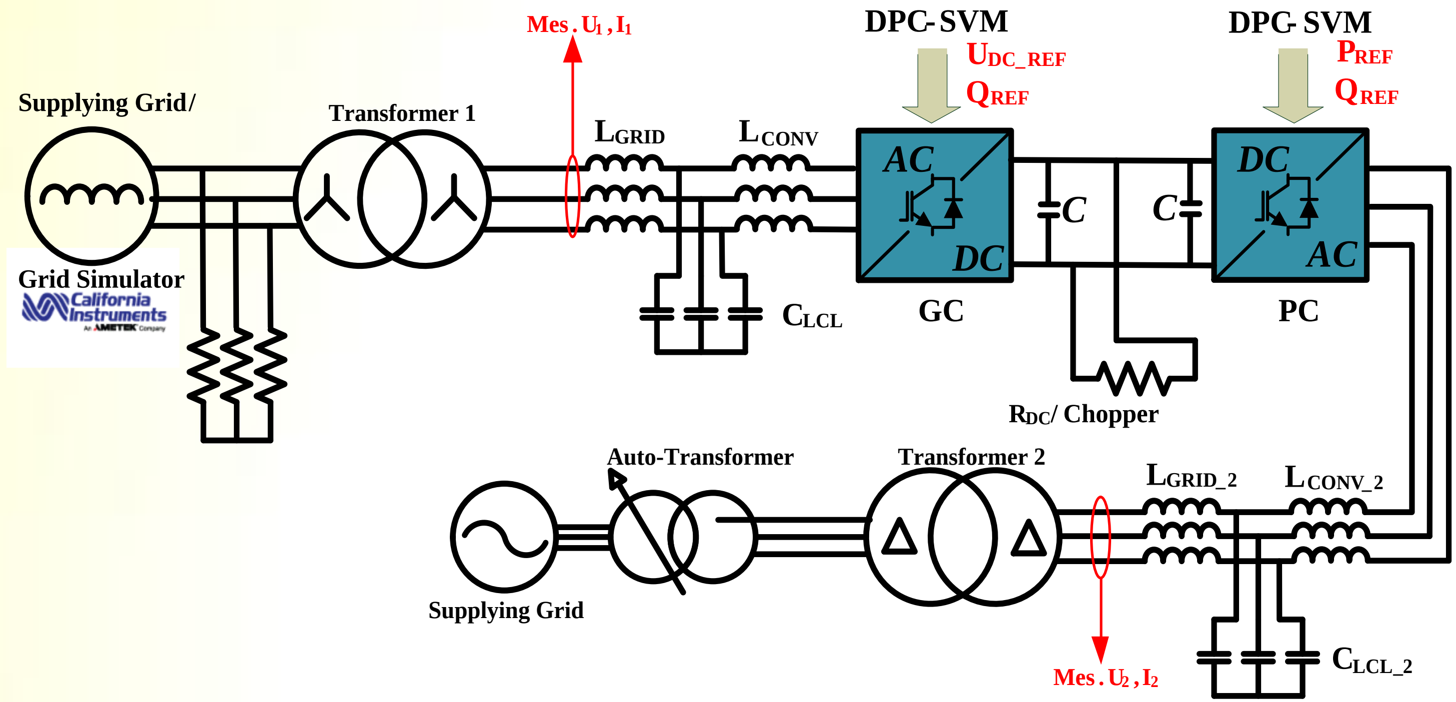
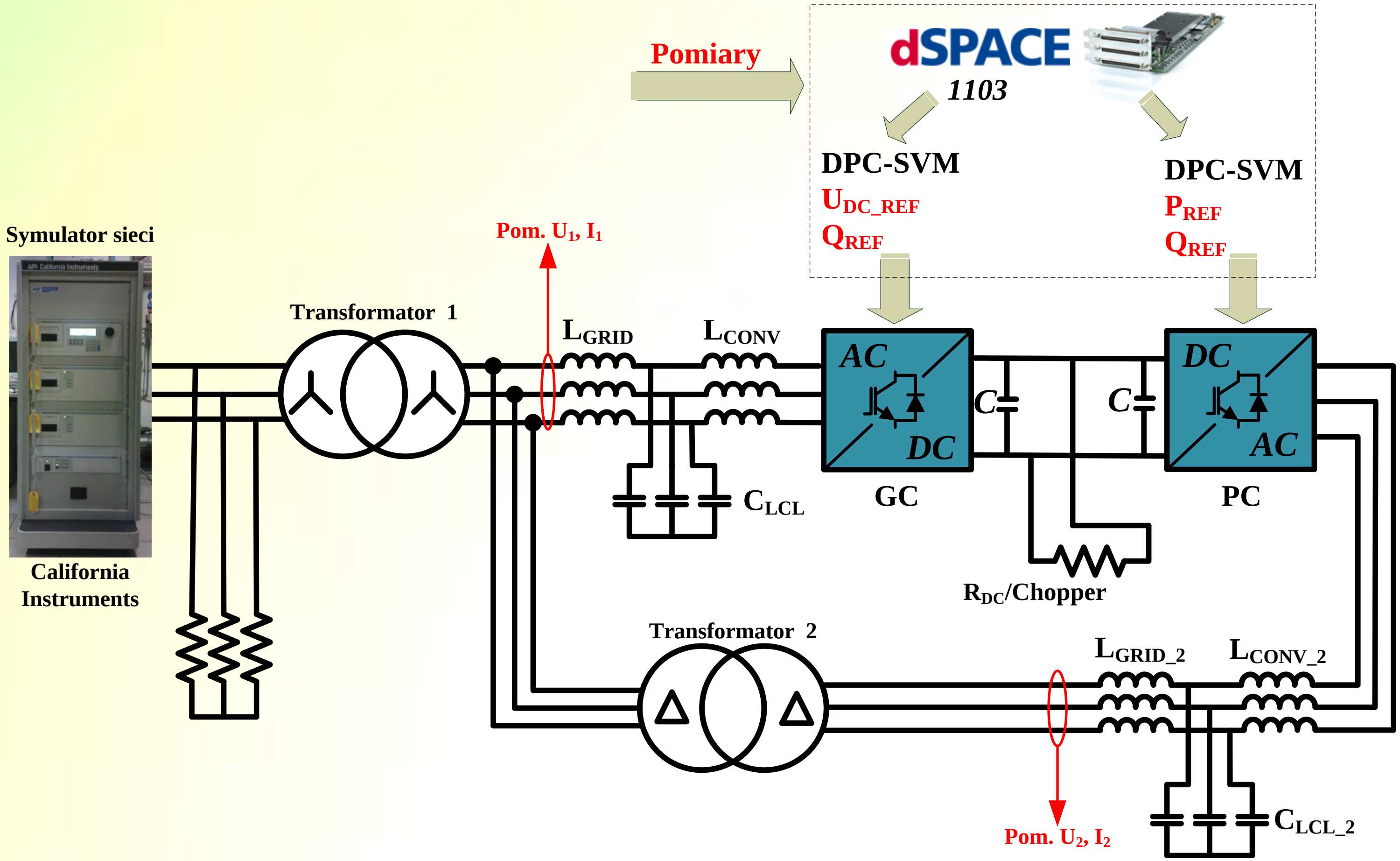
- **Active Rectifier**



- **Back-to-Back (Energy Transfer)**



Elaboration of three-phase AC/DC converter (series 5 - 400 kVA) resistant under different grid disturbances – Green Converter



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5-15 kVA Experimental Results

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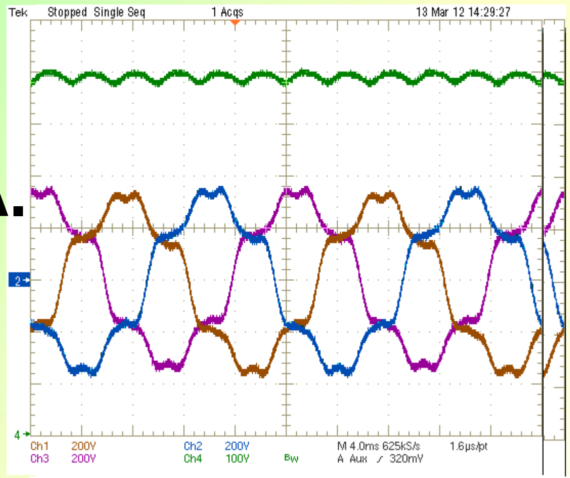
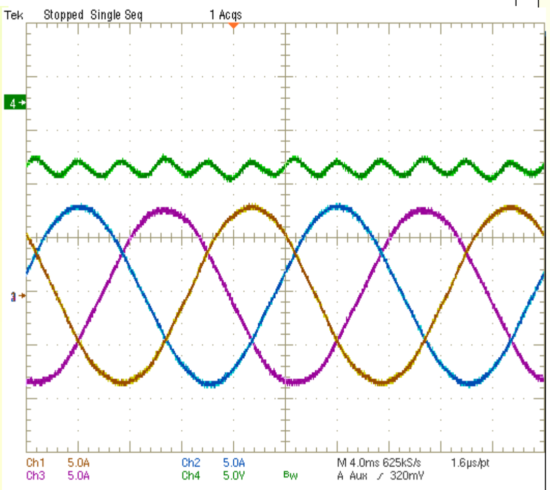
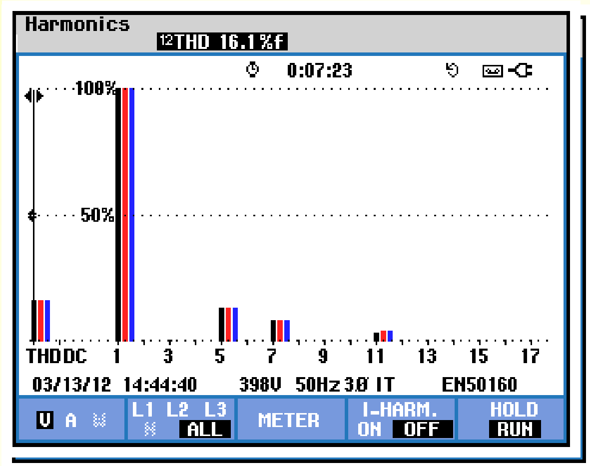
A.



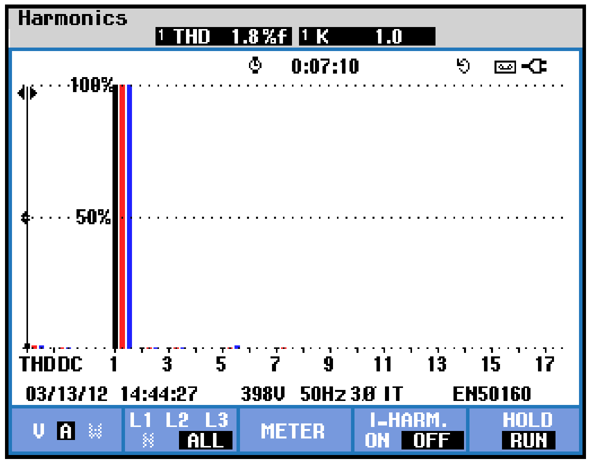
B.



C.



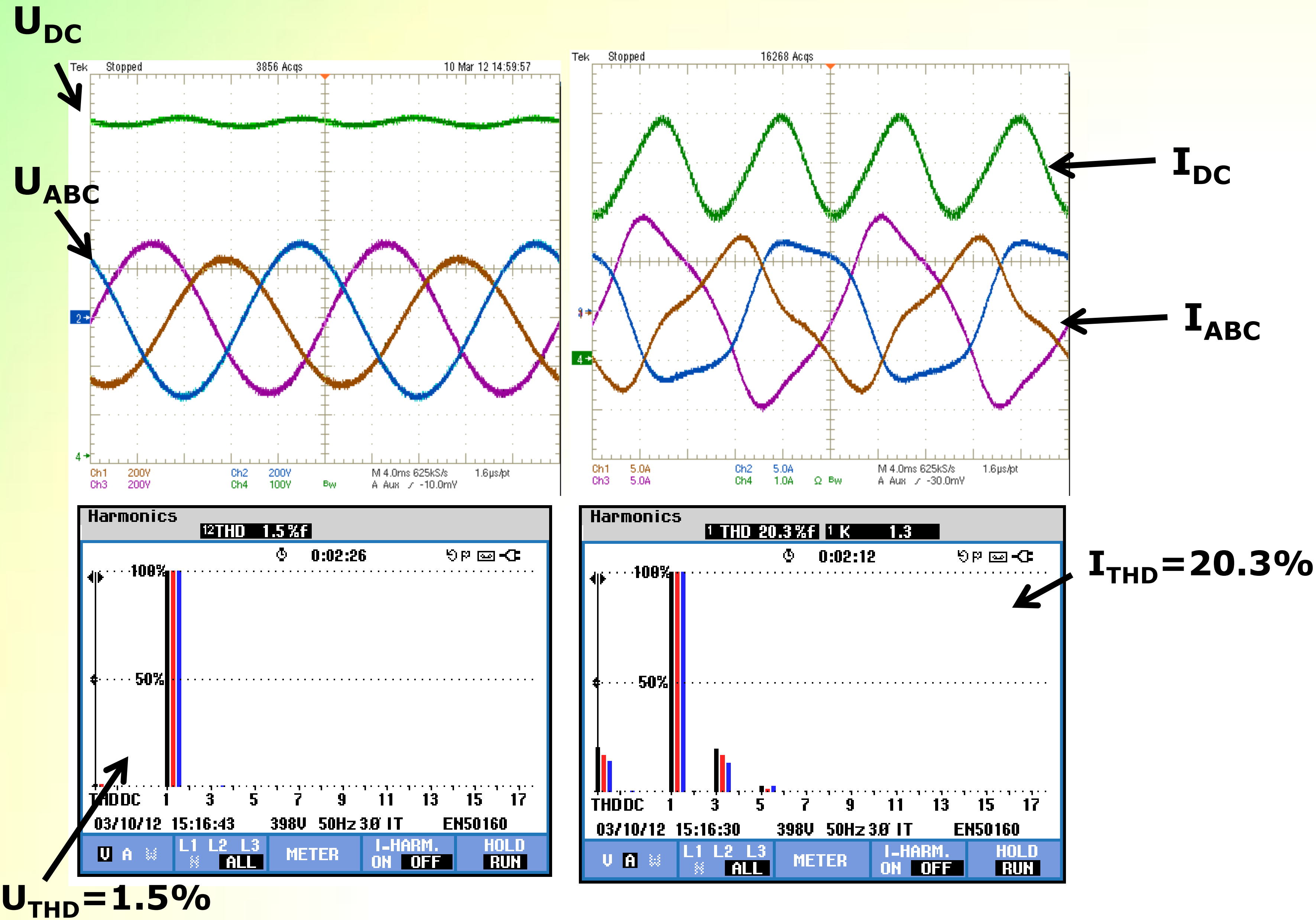
D.



A – Grid Voltage, U_{DC} Voltage
B – converter currents, I_{DC} current
C – THD of voltage (15.9% / 16.1%)
D – THD of current (22.3% / **1.8**%)

Generating operation of the grid conected AC-DC Converter (GC) with supplying voltage distorted by higher harmonics (15% of 5th, 10% of 7th and 5% of 11th harmonics)

Dips Compensation (5-15kVA)



Voltage dip (30%) in phase A, without dips compensation algorithm

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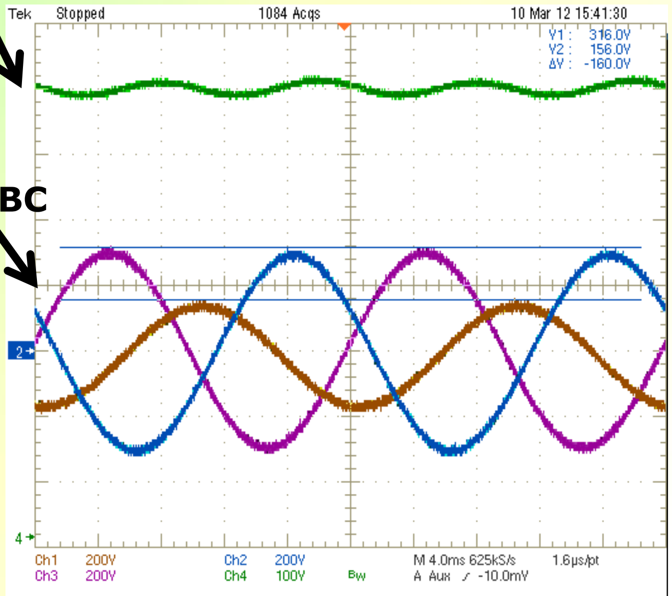
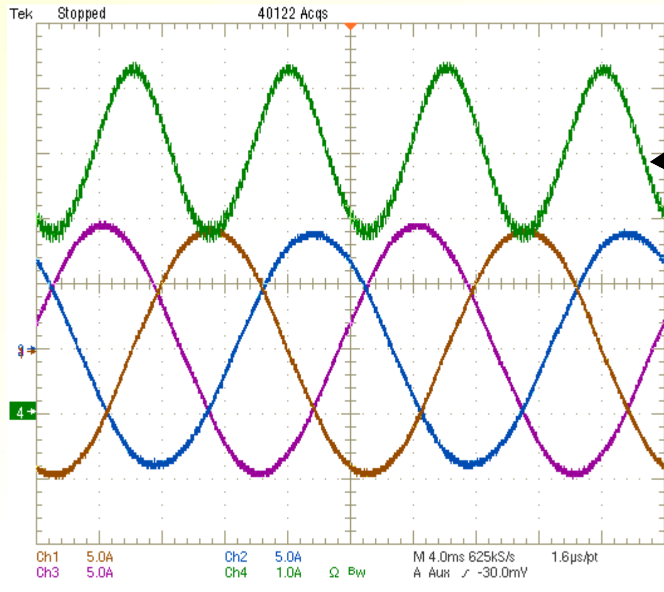
Dips Compensation (5-15kVA)

U_{DC}

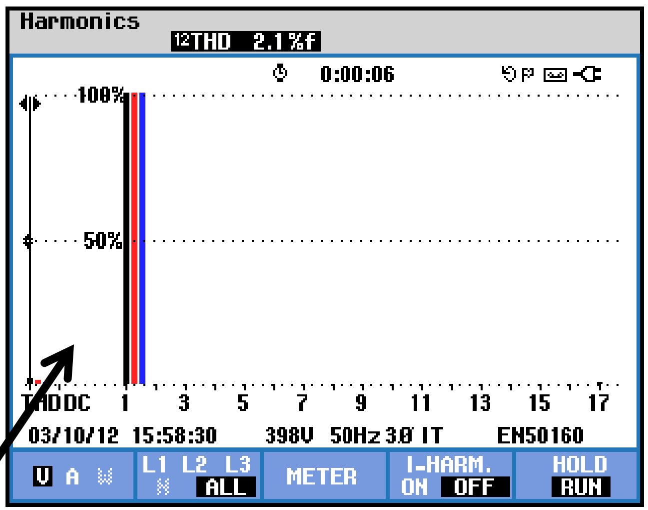
U_{ABC}

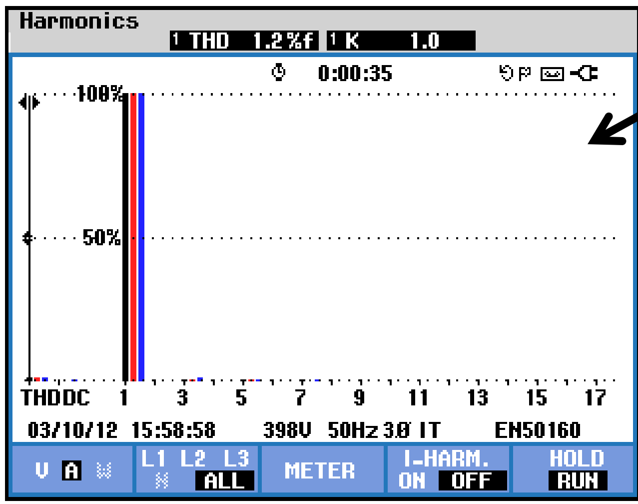




I_{DC}

I_{ABC}





$I_{THD}=1.2\%$

$U_{THD}=2.1\%$

Voltage dip (50%) in phase A, with dips compensation algorithm

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55kVA Tests in Small Water Plant

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Conclusions

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- Simulation and experimental results shown stable operation of the Grid Connected Converter (GC) during grid voltage disturbances, additionally modules in algorithm gives ability for higher harmonics compensation.

- Experimental investigation has shown that presented control method can be improved for better operation with higher grid impedance value.

- Presented method is promising control algorithm for growing number of GC AC-DC power electronic converters operating as an interface between the grid and Renewable Energy Sources (RES) or Active Loads (AL).

- The main achievements is a novel control structure applicable to standard, serially produced converters.

"Everyone needs an energy"!

Energoelektronika

More information:
www.isep.pw.edu.pl/ICG

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