www.weset-project.eu

Mechatronics in Wind conversion process

Module 3

Introduction to Mechatronics in Wind conversion process

Lesson 1

Co-funded by the
Erasmus+ Programme
of the European Union

Learning Outcomes

At the end of this lesson the students will be able to :

- *Understand the importance of mechatronics contemporary wind turbine 'designs'*
- *To identify the different mechatronic components in a wind conversion process.*

Co-funded by the Erasmus+ Programme of the European Union

Objective

In this part of the course we will discuss the issues arising in the integration of wind energy generators, and how mechatronics plays an essential role in its design and operation.

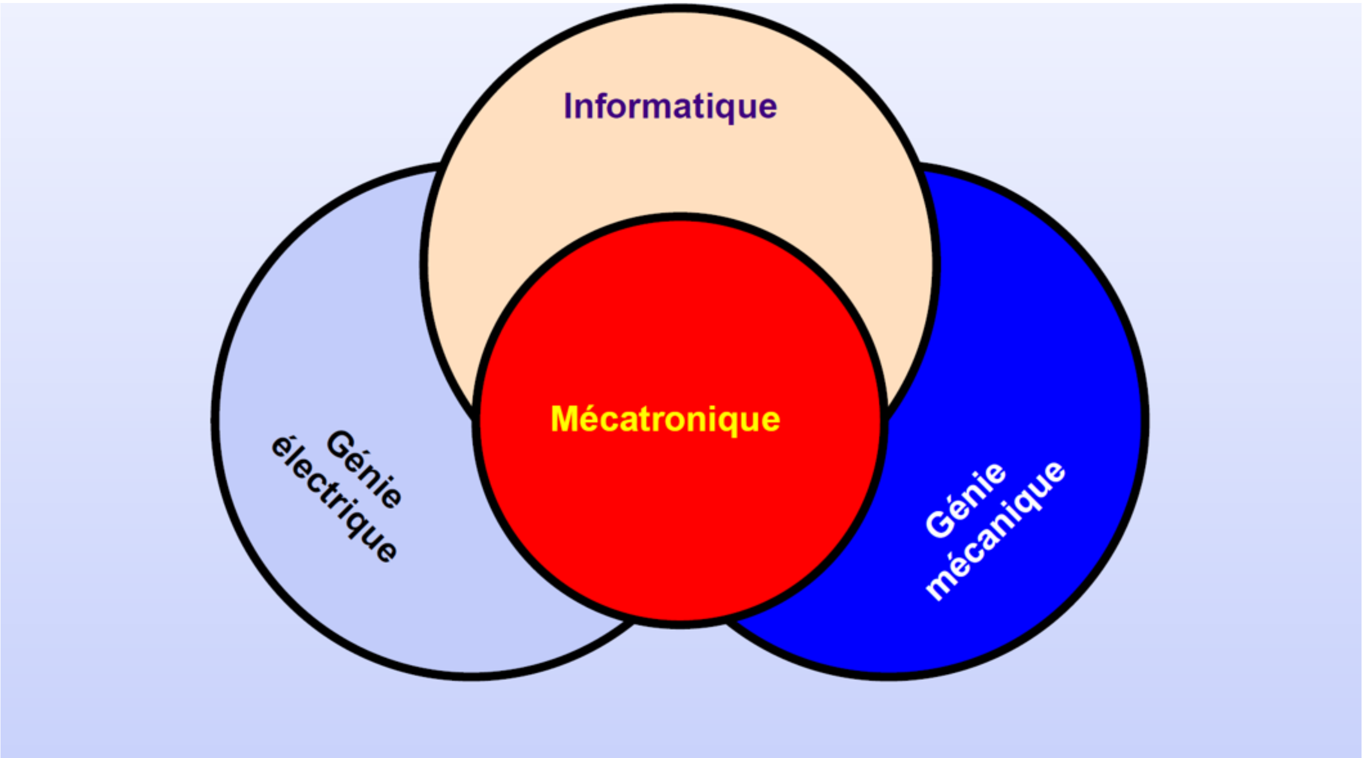
Co-funded by the
Erasmus+ Programme
of the European Union

Technical Contents

1) Introduction to Mechatronics
2) Mechatronics in the Wind Conversion Process

Co-funded by the
Erasmus+ Programme
of the European Union

2- Introduction



Definition :

Approach to the synergy integration of mechanics, electronics, automation and computing in the design and manufacture of a product in order to increase and/or optimize its functionality

Co-funded by the Erasmus+ Programme of the European Union

What is mechanonics?

Definition 1: Mechatronics is the integration of: Electronics-automatic-Computers (microcontrollers, DSPs, etc) in order to control different mechanisms ranging from nano to macro.

Definition 2: Mechatronics is the integration of: Electronics-control-Information Technology to solve mechanical engineering problems. It consists of a bonding between mechanical engineering and electronic control

Definition 3: Mechatronics is the science that integrates mechanical components with electronic control

4.History

- Word coined in 1969 by an engineer from the Japanese company, YASKAWA Electric corporation
- Combination of MECA (mechanical or mechanical and TRONIC (electronic)
- All rights to this word are granted to this company in 1971
- In 1982, YASKAWA abandoned its rights to the name in order to allow and encourage its use

Co-funded by the Erasmus+ Programme of the European Union

Stages in the development of mechatronics

- **Step 1** corresponds to the beginnings of the introduction of mechatronics (1969)

- **Step 2** corresponds to the early 80s.Emergence of the integration of different technologies

  Example introduction of opto-electronics and some designs using software/hardware integration

- **Step 3** corresponds to the early 90s with miniaturization of components.

  Notable developments include:

  - The development of smart machines
  - Miniaturization of components (micro-actuators, micro-sensors)

6. Multidisciplinary Approaches to Design

Mechatronics can be defined as the integration of:

- Sensors and measurement systems;
- Actuators
- Analysis of system behaviour
- Control Systems
- Electronics
- Microprocessor-based systems
- etc

Mechatronics refers to an interdisciplinary approach to engineering that deals with the design of products whose functions are based on the integration of mechanical, electrical and electronic components, connected by an architecture of Command

7 Key disciplines used in the design of mechatronic systems

- **Mechanics**
- **Electronics**
- **Control**
- **Computer science**

In order for the design to conform to the intended objective, the designer of a mechatronic system must assemble

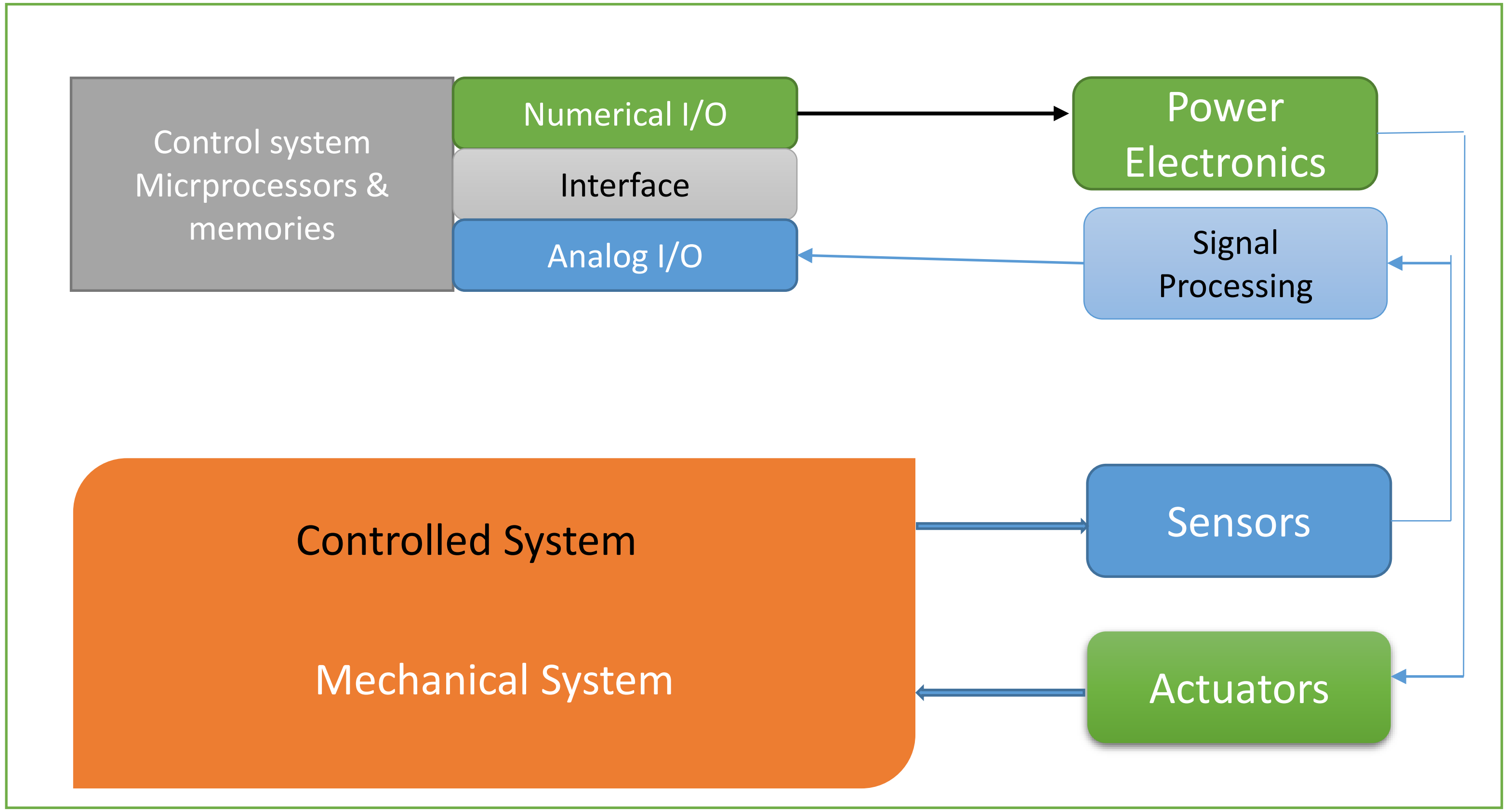
-Analog and digital circuits

-Microprocessors, microcontrollers, computers, etc.

-Sensors and actuators

-Control algorithms

8.General configuration of a mechanical system



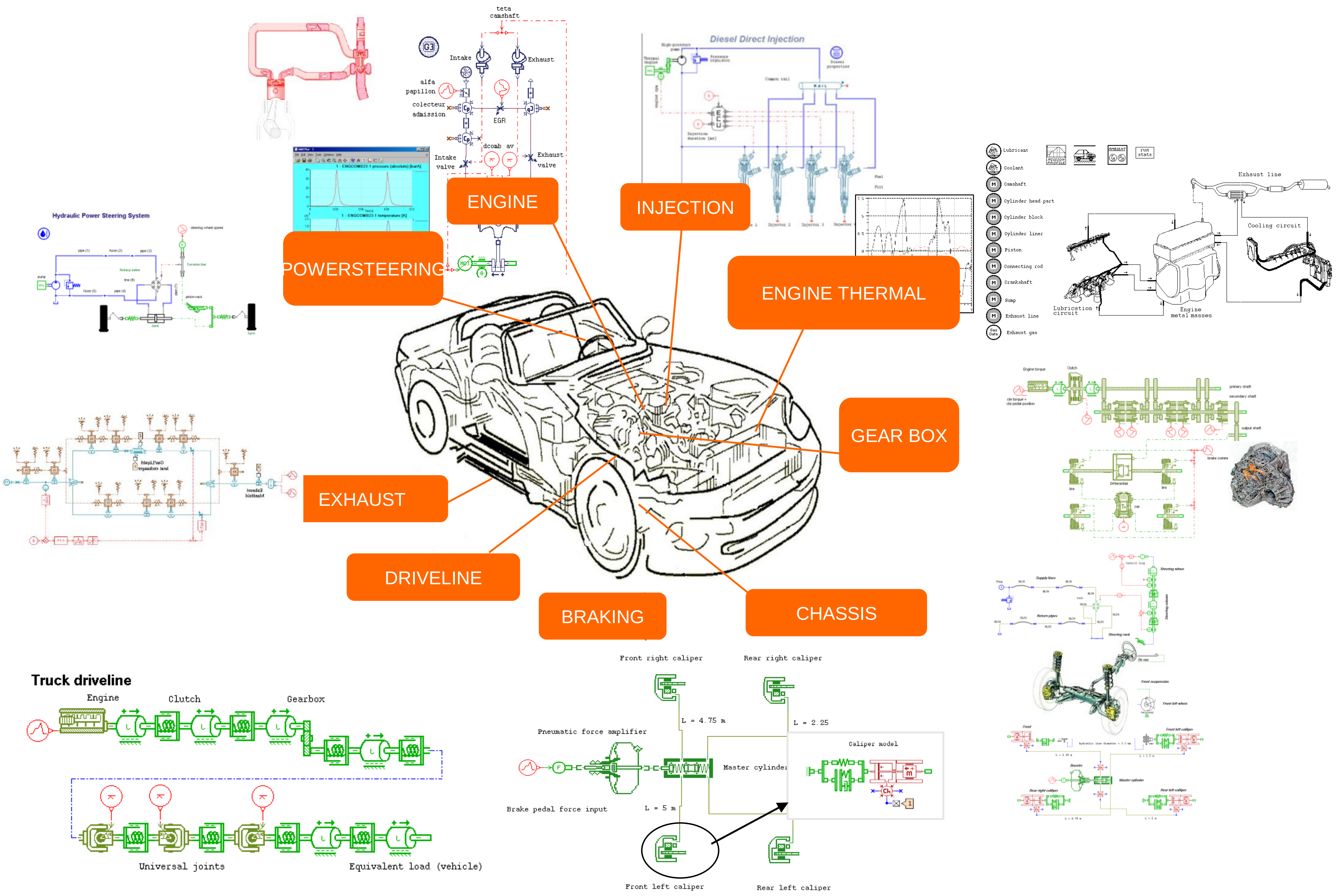
9 General configuration

- **Controlled system**: mechanical component generally controlled and in contact with the environment by all its sensors and actuators

- **Control system**: this is the essential organ of the mechanical system. Its role is to exploit the information from the sensors to provide the decisions to the system ordered for the completion of the desired task. It has three main components:
  - -Perception
  - -Representation of knowledge
  - -Control planning

Mechatronics is at the heart of the success of the various products: cameras, televisions, etc

Mechatronics in Automotive industry



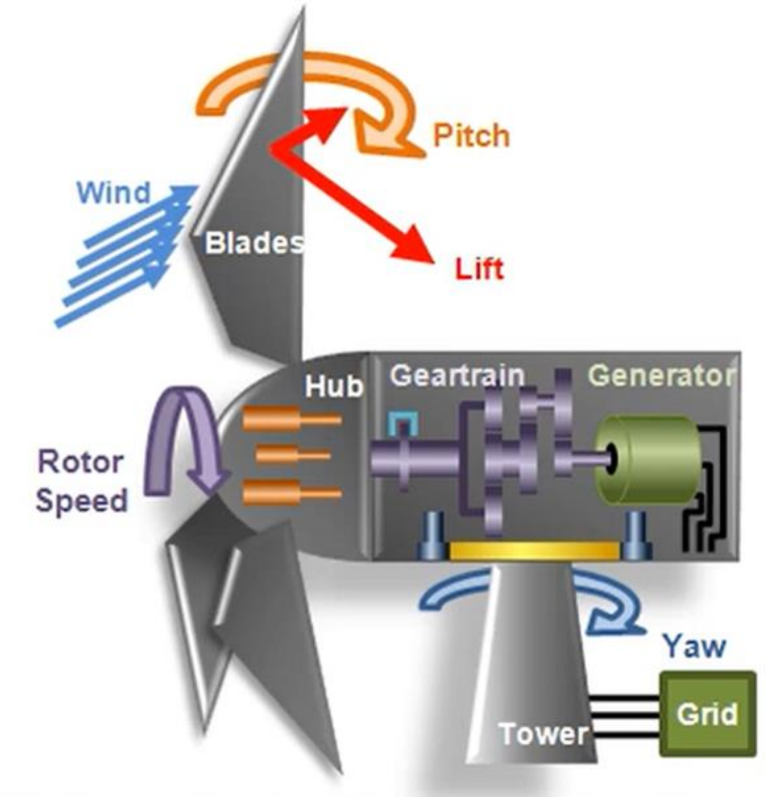
Co-funded by the Erasmus+ Programme of the European Union

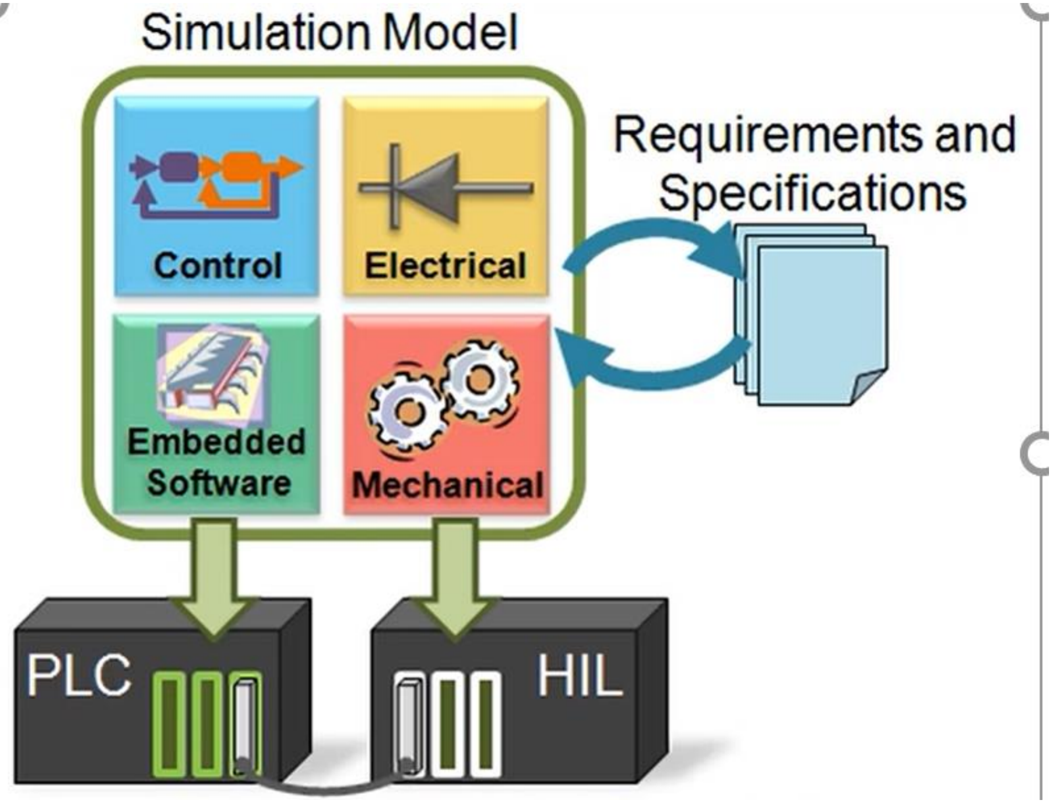
Mechatronics in wind energy 1/2

Applications where mechatronics play an essential role include wind turbine. This is a combination of the aerodynamics of rotor design, the mechanics of the speed reduction system, the electromagnetism of the electric generator, the electronic power system for power conditioning of release and synchronization of the power provided to the network.

Each part of the system must be designed in conjunction with other systems to achieve the overall objectives of an efficient conversion of the energy produced, taking into account both hardware and efficiency constraints. In addition, wind turbine equipment has constraints that are different from other forms of equipment.

Mechatronics in wind energy 2/2





Mechatronics at the heart of wind turbines 1/3

Wind control, rotational speed, temperature, etc
Mechatronics not only improves the operation of wind turbines, but also their design and maintenance

Intelligent systems on board wind turbines allow preventive maintenance to be carried out. The response time of technicians on site is thus reduced.

Mechatronics at the heart of wind turbines 2/3

In Wind Turbines movements and operations are carried out automatically, thanks to the different mechatronic elements that are installed within these machines. They contain no less than 400 sensors.

- One of the main challenges of the wind industry has been to reduce the costs of electricity generation, that now competes and even outperforms fossil fuels and nuclear power. Manufacturers have therefore focused on increasing the performance and reliability of the machines to optimize their maintenance and their lifespan. This is the role of mechatronics, as alliance of mechanics, electronics and computer science. It allows, for example, to measure changes in wind speed before it reaches the wind turbine, using Lidar (light detection and ranging) laser sensors, to make preventive adjustments.
- Always with the objective of reducing costs, the turbines have changed over the years. The control of the various mechanisms has become even more crucial. The gondola, the nerve heart of the wind turbine, houses several elements: the generator that generates electricity, but also the pitch system (the engines operating the blades) and the yaw system (the engine directing the gondola).
- These different components receive instructions from the control computer, placed at the foot of the wind turbine and easily accessible, which processes all the information provided by the many sensors. At every moment, this control center follows the speed and direction of the wind, the orientation of the pod, the impact of the blades, and sends orders to operate the engines.

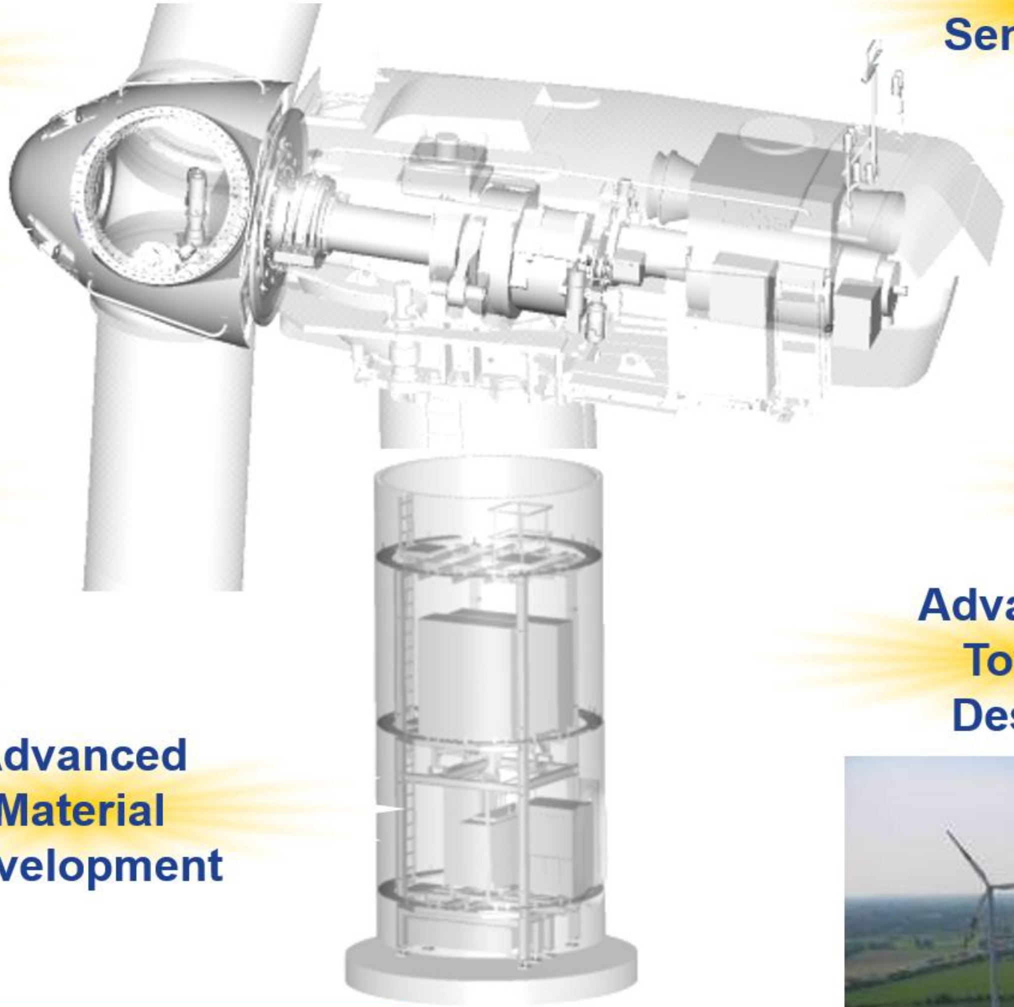
Mechatronics at the heart of wind turbines 3/3

- When a sensor detects an anomaly, such as an abnormal rise in temperature of an internal component, a brake is frequently applied to completely stop the rotation.
- Other hazards can be solved automatically. This is the case of frost that settles on the blades. Its detection is not provided directly, but by the appearance of a clam (unbalance) at the blades. The control center will then operate a heating system integrated into the blades.

Co-funded by the Erasmus+ Programme of the European Union

Co-funded by the
Erasmus+ Programme
of the European Union

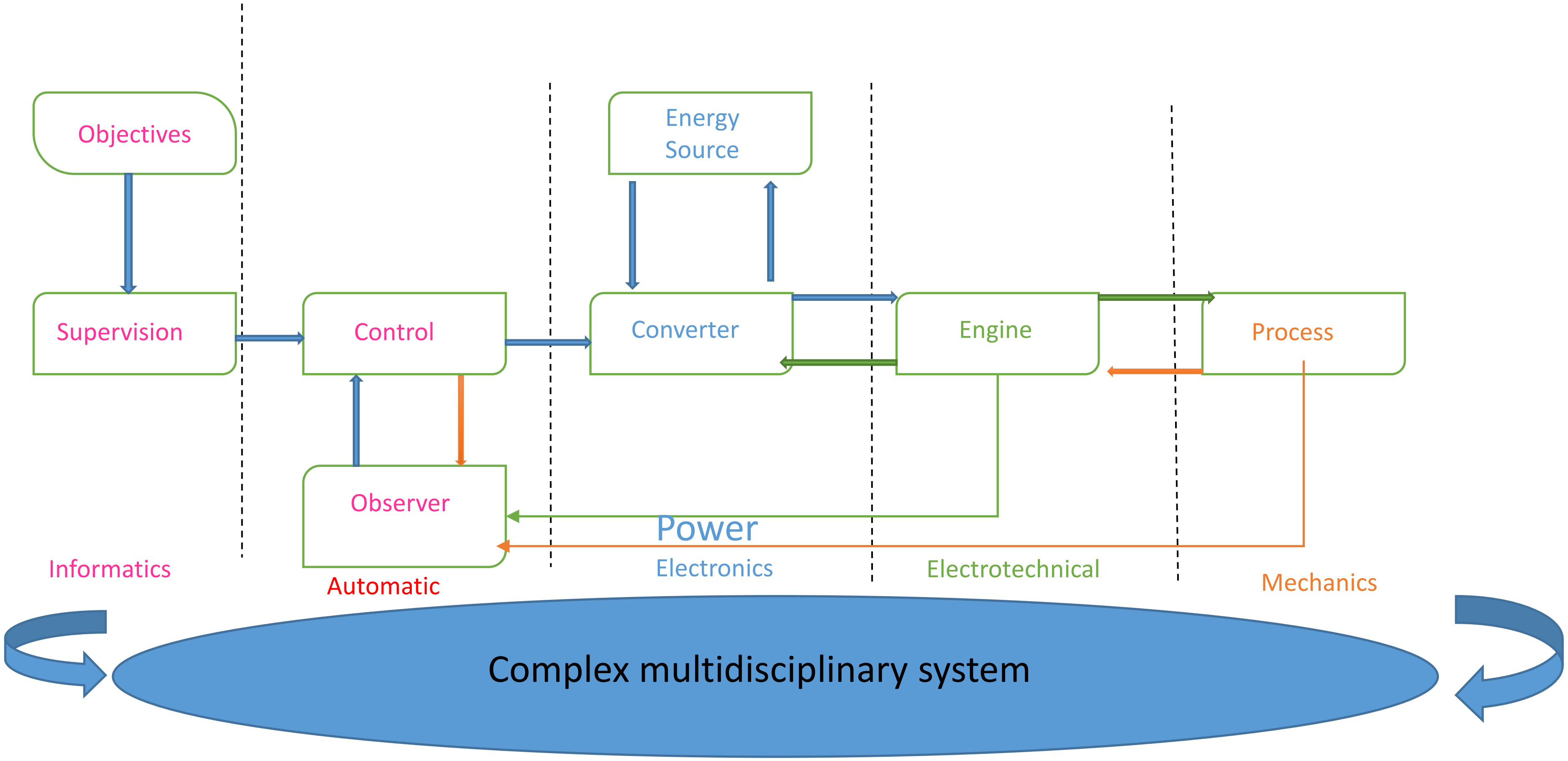
Advanced technology development



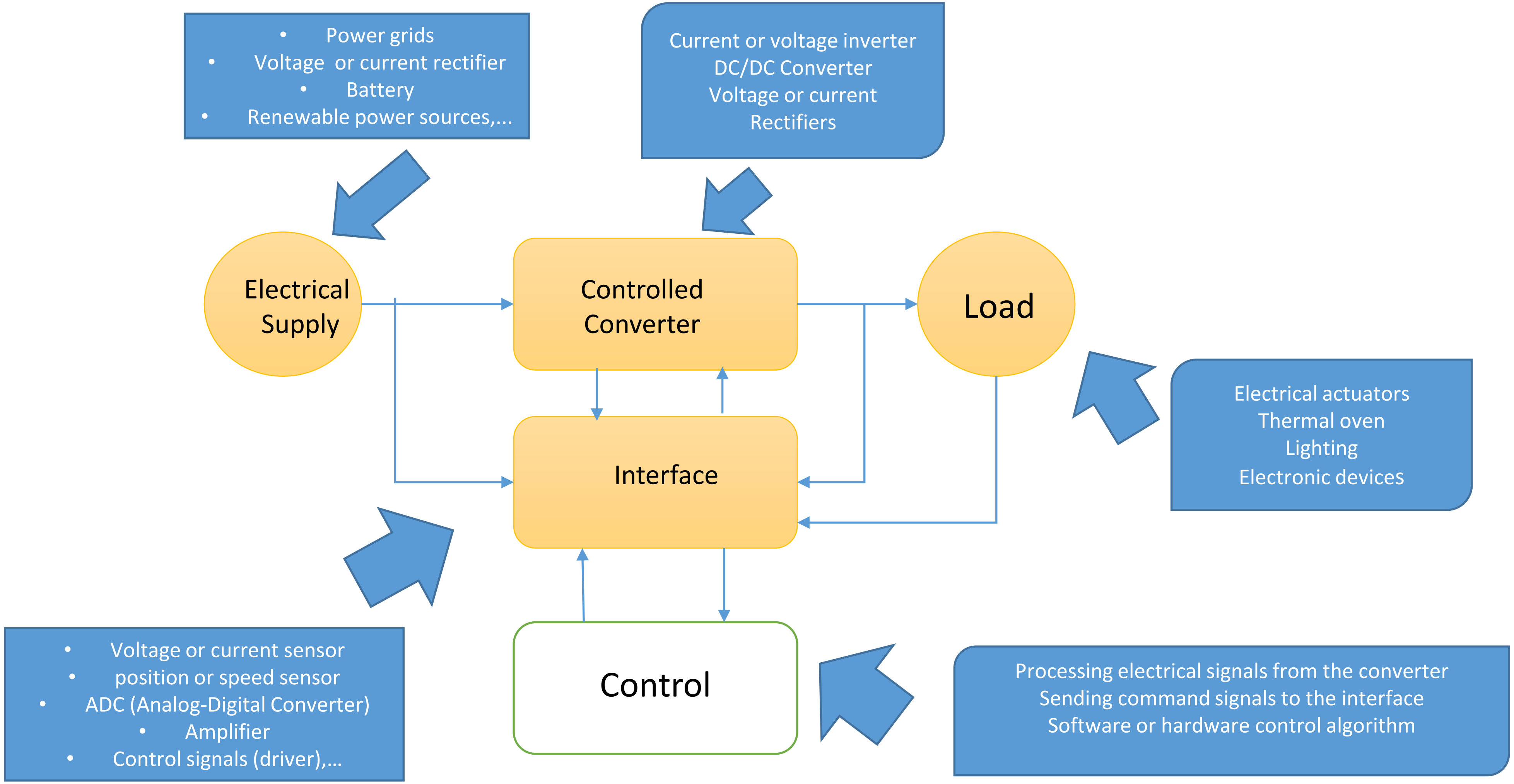
- Blade Construction
- Aerodynamic optimization
- Advanced Load Control
- Power Electronics
- Advanced Material Development
- Wind Sensing
- Compact Drivetrains
- Advanced Generators
- Wind Farm Management
- Advanced Tower Design

Possibilities are endless

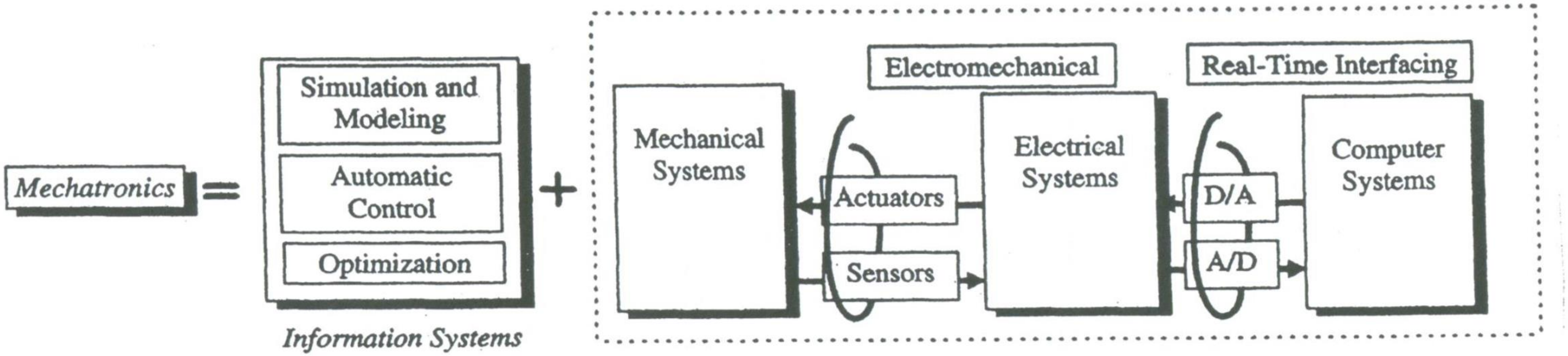
Mechatronic system



Mechatronic System



Key elements of Mechatronics System



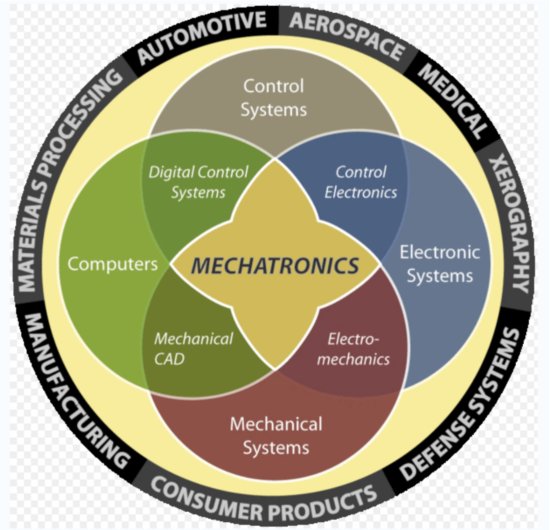
In conclusion

Mechatronics:

- Crossroads of different engineering specialties
- Recognized as a discipline in its own right
- Difficulty in transferring jurisdiction between different specialties

- Real needs in the industrial world
- Medium: simulation tools (AMESIM - LMS for example)

Applications: automotive, aeronautics, aerospace, wind , etc



References

• Mechatronics: Principles and Applications, G. Onwubolu (Elsevier Science, 2005);

• Mechatronics and Measurement Systems, D. Alciatore and M. Histland (McGraw-Hill, 2003);

• Mechatronic Systems: Modeling and Simulation with HDLs, G. Pelz (Wiley, 2003);

• Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 2nd Edition, W. Bolton (Addison Wesley Longman Ltd, 1999);

• Mechatronics System Design, D. Shetty and R. Kolk, (PWS Publishing Comp., 1997);

• Mechatronics: Mechanical System Interfacing, D. Auslander and C. Kempf (Prentice Hall, 1996);

• Mechatronics: Electromechanics & Contromechanics, by D. Miu (Springer Verlag, 1993).

Thank You for Your Attention!

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Contact: info@weset-project.eu weset.erasmusplus@uva.es

Co-funded by the
Erasmus+ Programme
of the European Union

WE SET

Co-funded by the Erasmus+ Programme of the European Union

Multiphysical modeling

Course 2

Mechatronics in Wind conversion process

Module 3

Introduction to Modelling and Simulation for Wind Energy

Lesson 2

Co-funded by the
Erasmus+ Programme
of the European Union

Learning Outcomes

At the end of this lesson the students will be able to :

- *Understand the importance of modelling and simulating using Multiphysics tools.*
- *To learn the basic ideas behind modelling wind turbines using Multiphysics tools.*

3

Co-funded by the
Erasmus+ Programme
of the European Union

Objective

In this part of the course we will discuss the importance of modelling and simulating wind energy generators using multiphysics, and how thes tools can play a significant role in its analysis and design.

4

Co-funded by the
Erasmus+ Programme
of the European Union

Technical Contents

1. Introduction

Motivations for multiphysical modeling of wind generators

2. Components of a Physical model

Power/Energy Notes

Representation of the energy chain of a complex system

3. Construction of a multiphysical model of wind generators using MODELICA

Modeling type

Causal and acausal modeling

Using MODELICA (tutorial)

Co-funded by the
Erasmus+ Programme
of the European Union

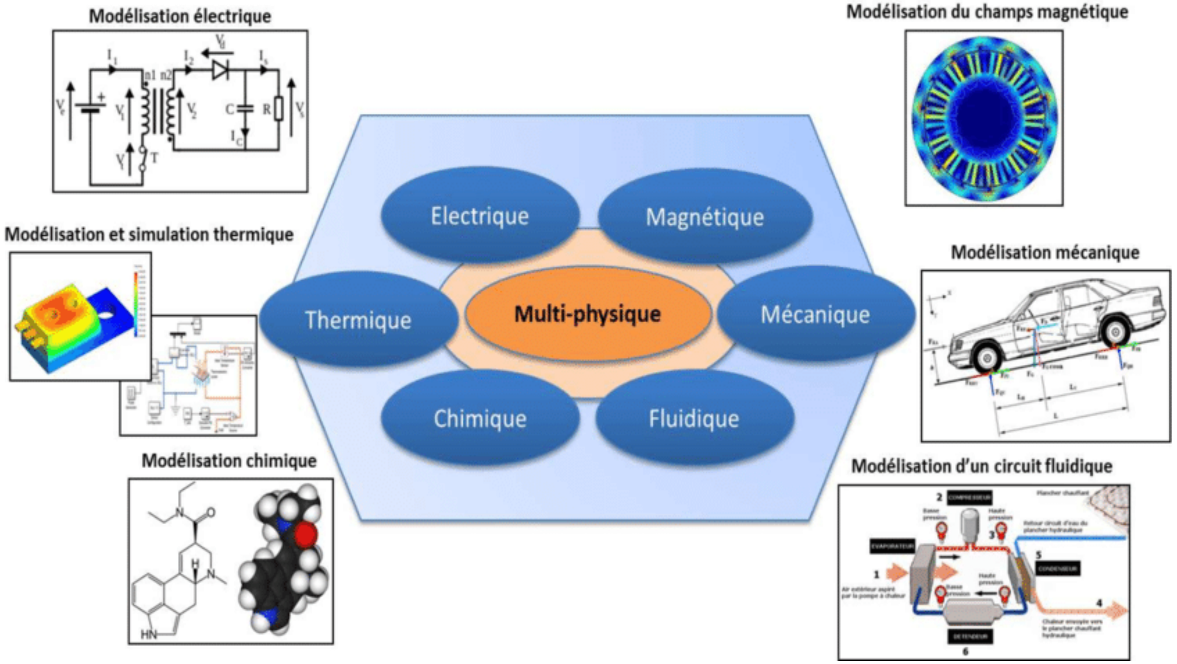
Introduction

Co-funded by the Erasmus+ Programme of the European Union

- The operation of most industrial products involves interactions between several physical phenomena of different natures

- In a simulation, it is often necessary to model these interactions to correctly predict the response of the product,

,



Co-funded by the Erasmus+ Programme of the European Union

Properties: Interests and motivation

The systems developed today are using more and more different technologies. This is why they can be called "multiphysical" or "pluritechnic".

To model the performance of a wind turbine it is necessary to determine the control of the different parts to obtain a given operation.

This problem is complex because it involves different physical domains: electric (engine control, energy management), mechanical (blades movements), aerodynamics, etc.

The goal is to build a model to make these different physical considerations interact is the principle of multiphysical modeling

Co-funded by the Erasmus+ Programme of the European Union

Definition: Multiphysical modeling

Multiphysical modelling is necessary to implement as long as a system is made up of sub-prime groups mobilizing technologies that use different branches of physics:

Electrical;
mechanical;
hydraulics;
Etc..

- The writing of principles relating to these different disciplines (electric laws, principles of dynamics, energy conservations) results in the writing of differential equations that must be solved in order to predict the behavior of the system that one Models.
- The tools of multiphysical modeling allow to link the knowledge patterns and behavioral laws of the different subset of the system to build a very complete model. That is the purpose of this course.

Reminders: Power/Energy Notes

Definition: Power/energy

- Energy: Energy measures a system's ability to modify a state or produce work.
  - the unit of an energy is the Joule (J) which is homogeneous to the product of a force by a length.

Power : is the amount of energy per unit of time.
Its unit is the Watt (W), which is homog'ene to the product of a force by a speed.
It is a scalar size that results from the product of two algal sizes: one is called flow and rated f (t); the other is called potential and is rated p(t). Generally it can be e-registered in the form:

$$P(t) = f(t) \times p(t) = \overrightarrow{f(t)} \times \overrightarrow{p(t)}.$$

Introduction

In addition to the block diagram to model continuous and invariant linear systems, the description of systems using SysML graphic language and multiphysical modeling are emerging. This is the time to clarify the concepts of causal and acausal modeling, and to emphasize the value of combining the use of SysML and That of Modelica in a model-guided system engineering approach, to which the languages "bond graph" and Modelica integrate fully, especially as SysML profiles.

We can also point out that a block scheme is not necessarily more telling than the differential equation system it represents. In addition, multiphysical models are easily reusable, thanks to the creation of libraries. The software used in multiphysical modeling allows to build abnormal models, unlike those that simulate block diagrams, which are causal models.

Co-funded by the Erasmus+ Programme of the European Union

Bond Graphs

- The description of the state of a multiphysical system requires the use of two sets of fundamental variables. Four of them are linked by mathematical relationships. They depend on the time t. Depending on the system studied, these variables may have more than one dimension: they are then expressed using vectors.

Two groupings are possible:

- Grouping 1 power variables, effort e and f flow energy variables, moment p and displacement q

- Grouping 2 kinematic variables, q displacement and kinetic f variable flows, moment p and f

Tutorial: Modelica for Wind Energy

Co-funded by the Erasmus+ Programme of the European Union

Motivations

- Why Modelica
- Why use Modelica in wind turbine modeling

Model with with Modelica

- General principle
- Language

Conclusions

- Potential inflows
- Boundaries/lack

Co-funded by the Erasmus+ Programme of the European Union

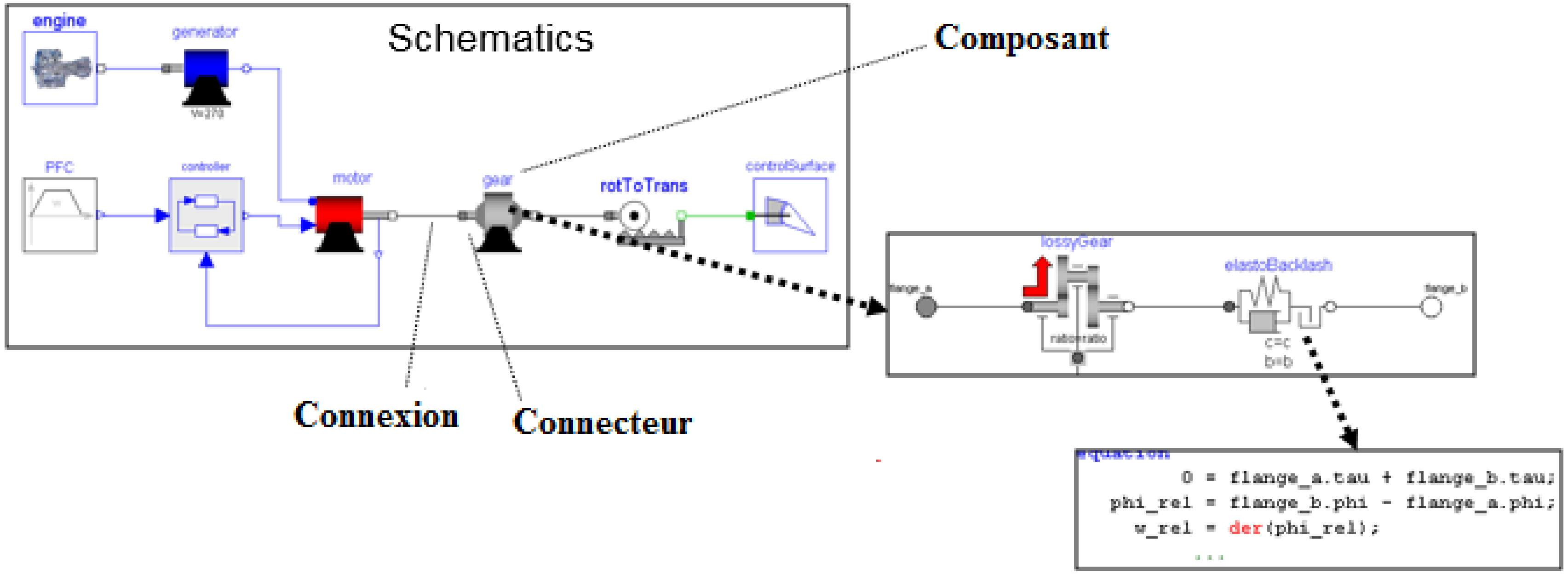
Modelica

- Modelica is a multiphysical modeling language of complex systems
- It is based on the acausal approach to modeling
- A class can be considered as a description of a family of objects sharing common properties.
- The different Modelica classes are:
  - Records
  - Function
  - Connector
  - Block
  - Model

Co-funded by the Erasmus+ Programme of the European Union

Structure of a modelica model

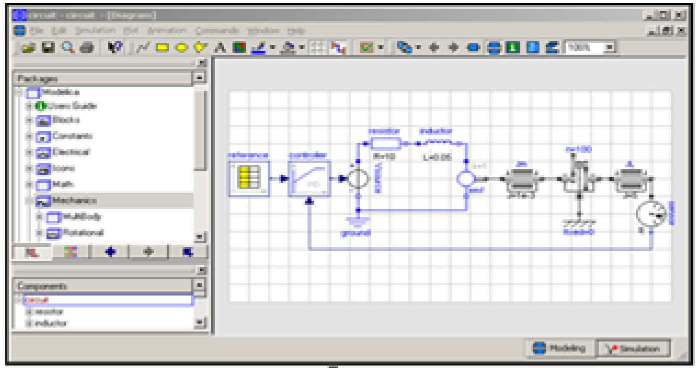
- Each icon represents a physical component. (electric resistance, mechanical device, pump, ...)
- A connection line represents the actual physical coupling (wire, fluid flow, heat flow, ...)



- A component is made up of connected sub-components (hierarchical structure) and/or is described by equations

Modelica Language and simulation environment

Graphic editor for Modelica models

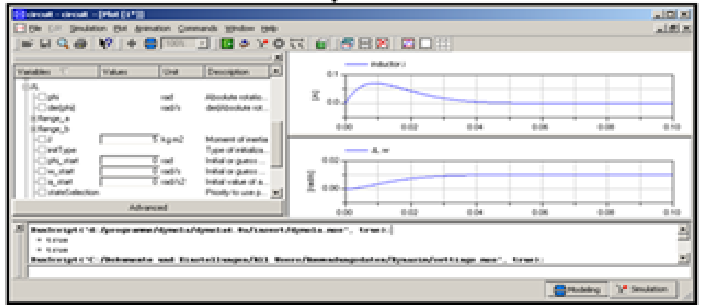


Text description

```
model circuit
  ;
  Modelica.Electrical.Analog.Basic.Resistor resistor(R=10) ;
  Modelica.Electrical.Analog.Basic.Inductor inductor(L=0.05) ;
  Modelica.Electrical.Analog.Basic.EMF emf(k=1) ;
  Modelica.Electrical.Analog.Sources.SignalVoltage Vsource ;
  Modelica.Electrical.Analog.Basic.Ground ground ;
  Modelica.Blocks.Continuous.LimPID controller ;
  Modelica.Mechanics.Rotational.Inertia Jm(J=1e-3) ;
  Modelica.Mechanics.Rotational.IdealGear n(ratio=100) ;
  Modelica.Mechanics.Rotational.Fixed fixed ;
  Modelica.Mechanics.Rotational.Inertia JL(J=5) ;
  Modelica.Mechanics.Rotational.Sensors.SpeedSensor sensor ;
  Modelica.Blocks.Sources.CombiTimeTable reference ;
```

Modelica language

Traduction C language for simulation



Motivations : Why Modelica (1/2)

- A declarative, object-oriented language
- A language specially adapted to modeling systems
- Applying to all areas
- UML modela- for modellers?
- A language to describe hybrid models
- 'Hybrid' - discrete -continuous

Motivations : Why Modelica (2/2)

- Towards a standardized modeling language

Specifications are standardized

The only obligation of computer tools (compilers) is to comply with these specifications

Applications to date

-Mechatronics, Electronics, Power Systems, Hydraulics, Aerodynamics..."

- Modelica comes from a community of modellers, familiar with the object approach (Scandinavian school)

Motivations: why model wind turbines with Modelica

Thanks to Modelica, the model of the wind turbine and its simulation can be expressed in a unified language at the same time

Understandable by the modeller

It's computable

- neatly characterizing all manipulated objects (semantics)

Modelica: general process (1/2)

- Defining a system model
- 'component-oriented'
  - Discrete and/or continuous state variables
- Dynamic (continuous time) described by
  - Differential equation
  - Program
- Inheritance between components
  - Reusable components (component libraries)
  - 'model' - component assembly
- Graphic editors

Co-funded by the Erasmus+ Programme of the European Union

Model / Simulate with Modelica: general process (2/2)

2. Setting the parameters of a simulation

3. compilation of the set model

Flattening the object model

Production of a hybrid EDA system

4. Running the simulation program

Exploitation of hybrid EDA solvers adapted to the problem

Modelica: Language

Key concepts

A list of basic types of constructions

Real, Integer, String, Boolean

"Array, Enumeration"

A general concept of class (class)

Special class shapes

model, record, block, connector, type, package, function

Dynamics: time is constantly changing. It is shared by all the components of a model

Modelica: Classes

A class defines the properties common to the components attached to them

Takeover of existing class properties (multiple inheritance)

Such as what

Specialization (more specific types, parameter evaluation)

State variables

Variability

Constant: value imposed in the model (immutable for any simulation)

Parameter: free value to be specified at the beginning of the simulation (immutable for this simulation)

Discreet: real value that can change during discrete events

Causality

'input': value to be derived from an output variable: value produced

'flow'

Flow: variable of the flow genre (see connectors)

Equations

List of equations linking state variables

Define the dynamics of continuous variables

Algorithm

Description of a program

Allows you to calculate discrete variable values

Co-funded by the Erasmus+ Programme of the European Union

Modelica: special classes

Type: defines a type, by extension of a predefined type for example

Example:

typeVoltage - Real (quantity" "Voltage"

•connector: defines a connector

State variables are potentials

When two connectors are connected, the connection requires that the potential variables are equal

State variables are flows (flow)

When two connectors are connected, the connection requires that the flow variables have their sum equal to 0

No associated equations

Example:

Connector
Pin Voltage v;
flowCurrent i;
endPin;

- model: class that cannot be operated as a connector

Examples:

An abstract model:

```
partial model TwoPins
        Pine p, n;
        Voltage u;
         Current i;

equation
        0 - p.i- n.i;
        u - p.v -n.v;
       i - p.i;

End TwoPins;
```

Concrete model:

```
Model Resistor
Extends TwoPins;
Parameter ResistanceR;
equation u = R*i;
 end Resistor;

Model Capacitor
Extends TwoPins;
Parameter Capacitance C;
equation C*der(u) = i;
End Capacitor;
```

Examples :

Model Sinus Source
Extends Two Pins;
Parameter Frequency F;
Parameter Voltage A;
Protected
 Constant Real PI - 3.14159265358979;
equation u - A - sin (time - 2-PI-F);
End SinusSource;

Block: class to contain at least one causal variable (input or output), not usable as a connector

Function: class block that does not contain an equation and contains no more than one algorithm

```
functionDistance
        parameterInteger N;
        inputReal[N] p1;
        inputReal[N] p2;
        outputRealresult;

algorithm result: 0;
For i loop result: end for;
result: sqrt(result);

End Distance;
```

Co-funded by the
Erasmus+ Programme
of the European Union

References

https://www.modelica.org/

http://doc.modelica.org.

http://mbe.modelica.university/.

Thank You for Your Attention!

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Contact: info@weset-project.eu weset.erasmusplus@uva.es

Co-funded by the
Erasmus+ Programme
of the European Union

www.weset-project.eu

Mechatronics in Wind conversion process

Module 2.3

Power Converters in Wind Energy

Lesson 3

Co-funded by the
Erasmus+ Programme
of the European Union

Objective

In this part of the course we will see the advantages and disadvantages of different converters used in the conversion of wind energy

Co-funded by the
Erasmus+ Programme
of the European Union

Learning Outcomes

At the end of this lesson the students will be able to :

- *Understand wind turbine technology i.e. generators, converters, connection of wind turbines to the network grid.*
- *Appreciate the development of design needs and innovation in the international market.*
- *Present, discuss and argue converter selection aspects of wind conversion process.*

Co-funded by the
Erasmus+ Programme
of the European Union

Technical Contents

1) Introduction : The connection of a wind turbine (WT) to the grid
2) WTS Power configurations
3) Grid Power Converter Topologies

Co-funded by the
Erasmus+ Programme
of the European Union

Power converters for Wind Energy

Different topologies of converters are used for the power conditioning of wind turbine generator systems.
Each converters provides certain advantages and disadvantages.
Only unidirectional converters based on diode rectifiers and bidirectional topologies of back-to-back converter are commonly used in commercial wind generator systems.

In this part of the course we will see the role of the following converters in the conversion of wind energy:

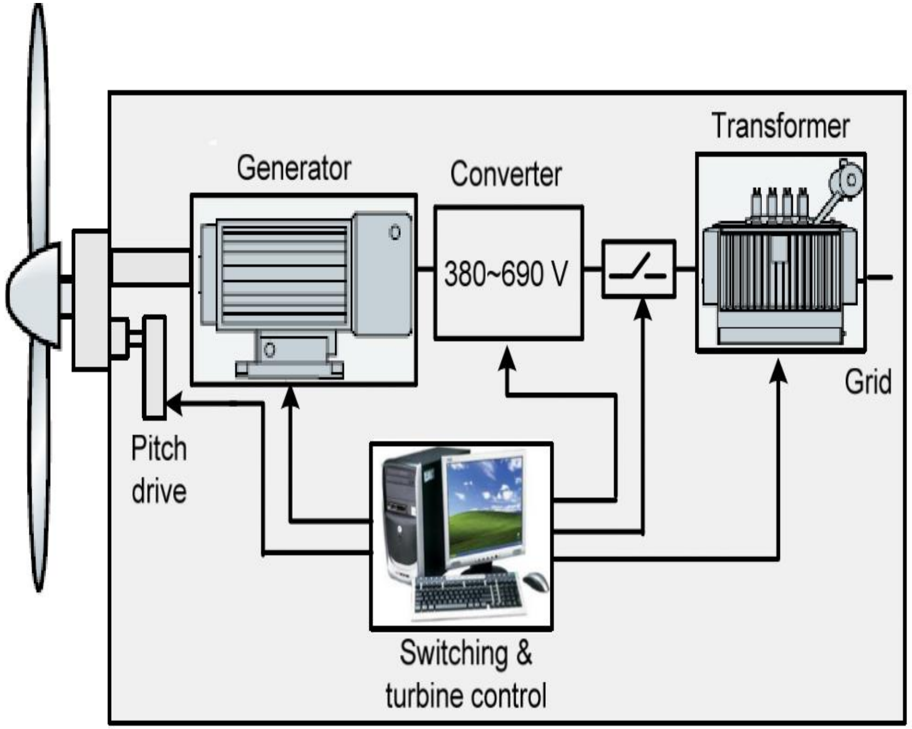
- Diode rectifier based converter ’
- Back to back converter
- Matrix converter
- Z-source converter
- Improved Z-source converter
- Cycloconverter
- Multilevel converters

Introduction

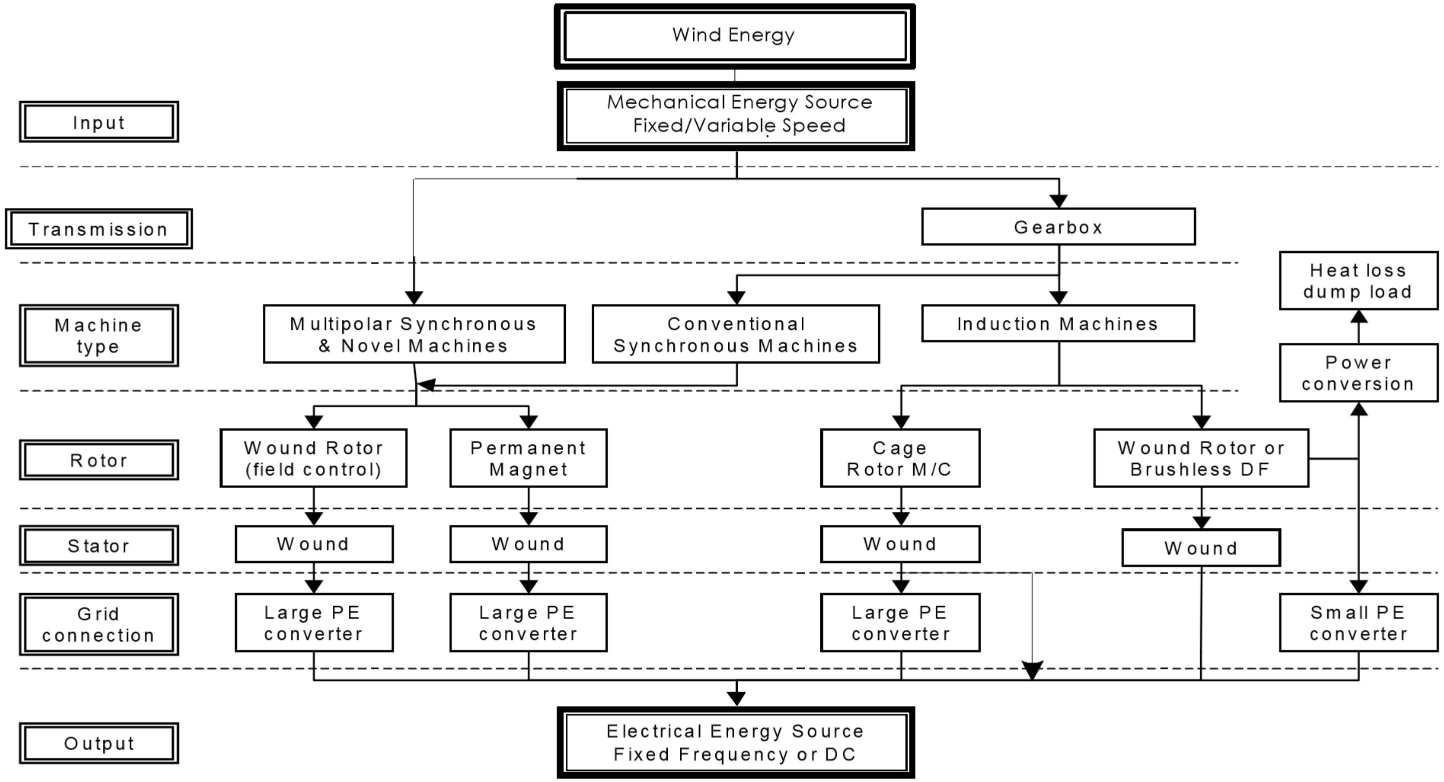
The traditional converter voltage level is between **380 to 690 V** due to the low generator voltage and the use of the two-level converter topology.

To reduce electrical losses, a supply frequency (50/60 Hz) is commonly used in the wind power generation system (usually installed inside the turbine nacelle). To increase the voltage at medium voltage (for example 11-33 kV) a transformer was required: however, it is heavy and bulky which considerably increases the weight and volume of the nacelle as well as the mechanical stress of the tower.

Nowadays, thanks to the power electronics, the components can accept higher currents and voltages, the power loss decreases and the devices become more reliable for power control on the megawatt scale. Recent progress has led to the development of new medium voltage converters which eliminate the transformer.



système de conversion d’énergie éolienne



Technological roadmap starting with wind energy / power by converting mechanical energy into electrical power

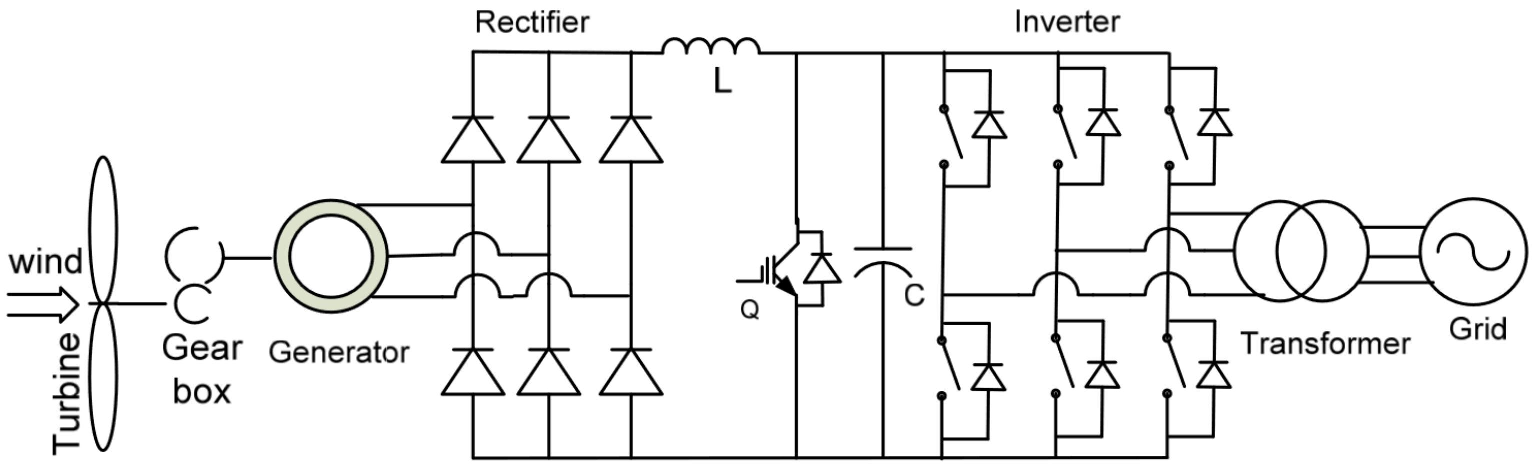
A technological roadmap starting with wind energy / power by converting mechanical energy into electrical power is presented. These are solutions with and without a multiplier as well as solutions with or without electronic power conversion. The electrical output can be either AC or DC. In the latter case, a power converter will be used as an interface to the network.

Converters in power generation

Over the past two decades, different topologies of converters have been studied for the power conditioning of wind turbine generator systems. All the converters offered have certain advantages and disadvantages. Only unidirectional diode rectifier converters and back-to-back bidirectional converter topologies are commonly used in commercial wind turbine generator systems.

Diode rectifier converter

In this converter system, AC power at variable frequency and at variable amplitude from the wind turbine generator is first converted to DC power by a diode rectifier circuit, then converted to AC power at a frequency and at a level of different voltage by a controlled inverter circuit.



Topology of the diode rectifier converter

Benefits:

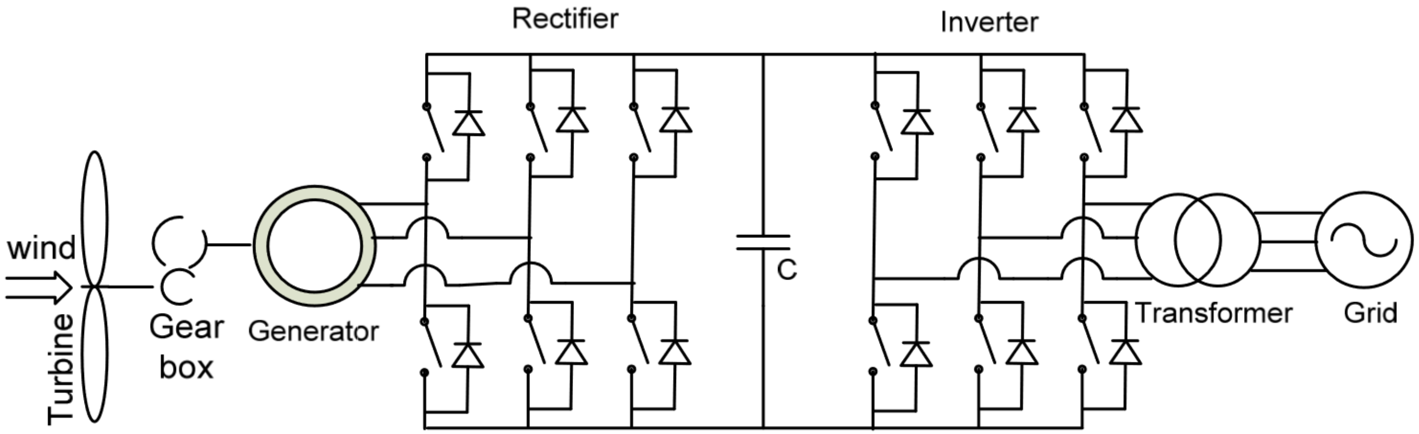
- Low production cost of the system and
- Simple to implement

Disadvantages:

- It produces a large amount of harmonics (input current), which affects the performance of the utility system
- Higher losses (output voltage) due to harmonics
- Unidirectional sense of power

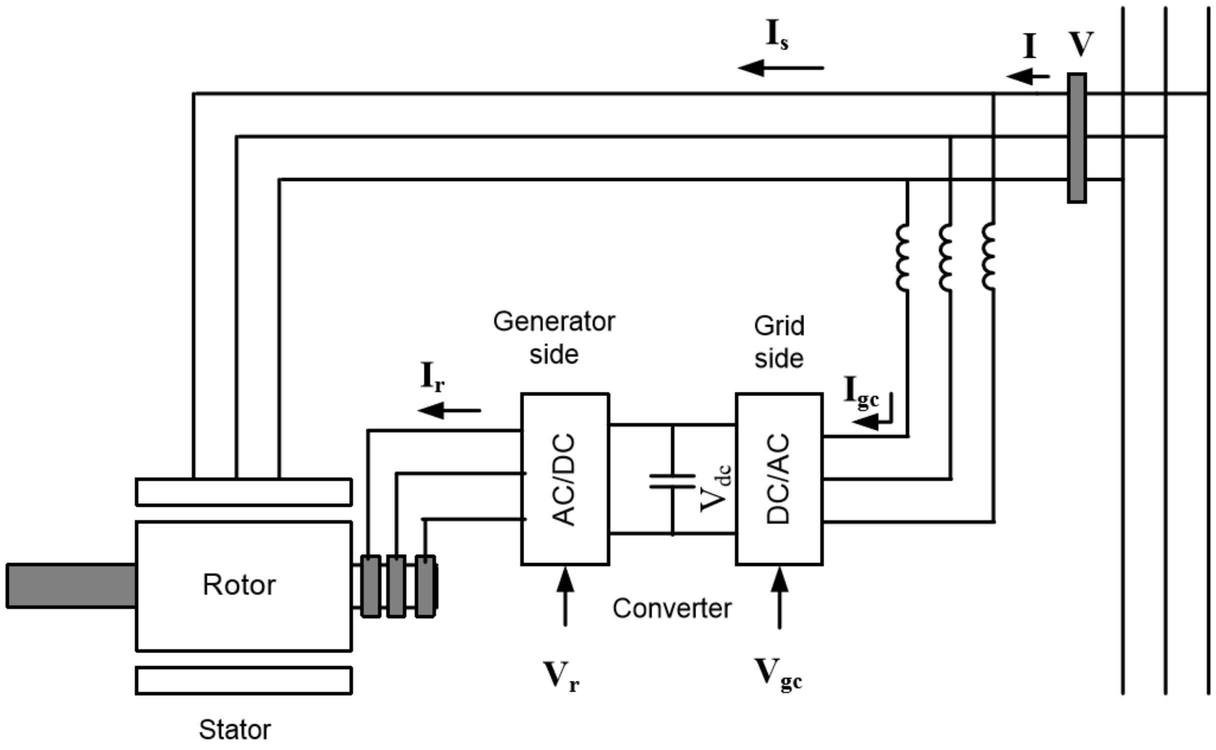
Back to back converter

The converter based on a controlled diode rectifier and a controlled inverter is called a ‘back-to-back‘ converter, which is made up of two converters with conventional pulse-width modulated voltage source (PWM).
It differs from the conventional converter as shown in the figure.
The controlled rectifier allows a bidirectional power flow. In addition, the controlled rectifier greatly reduces the input current harmonics and harmonic losses.
The line-side converter controls active and reactive power flow to the network and keeps the DC voltage constant, improving the quality of output power by reducing total harmonic distortion (THD).
The generator's side converter operates as a conductor, controlling the magnetization demand and the desired generator rotor speed. The decoupling capacitor between the line side converter and the generator side converter provides independent control capability of the two converters.



‘Back to back’ converter generator system

The back-to-back converter is of significant interest for the wind turbine system using the dual power induction generator (DFIG).



DFIG with back-to-back converter

Recall on the dual power generator

- A dual power generator (DFIG) composed of a wound rotor, an induction generator and an AC / DC / AC converter based on IGBTs.
- The stator winding is connected directly to the network while the rotor is supplied at variable frequency by the AC / DC / AC converter.
- Vr is the rotor voltage and Vgc is the lateral network voltage.
- The AC / DC / AC converter is essentially a PWM converter which allows the reduction of the harmonics present in the DFIG system controlled by the wind turbine.
- Crotor is the lateral rotor converter and Cgrid is the lateral network converter
- To control the speed of the wind turbine, multipliers or an electronic control can be used

Benefits:

- The back-to-back power converter is a bidirectional power converter
- The DC link voltage can be increased to a level higher than the amplitude of the trunk line voltage in order to achieve full control of the grid current
- The capacitor between the inverter and the rectifier makes it possible to decouple the control of the two converters, allowing compensation for the asymmetry on the generator side and on the grid side.
- Component costs are low (commercially available as a module).

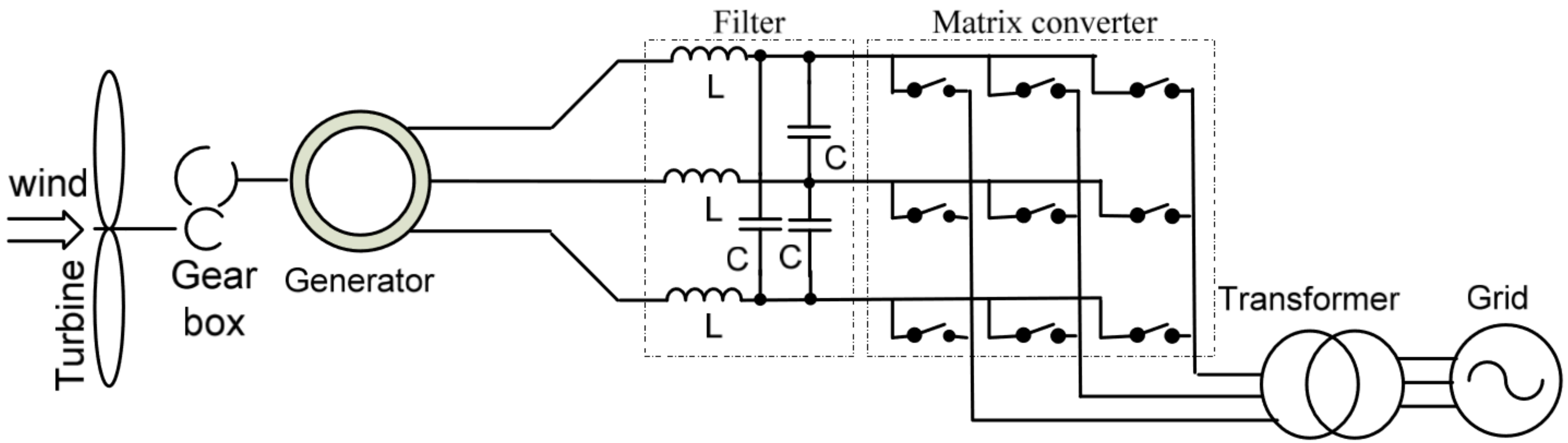
Disadvantages:

- Heavy, bulky DC link capacitor increases costs and reduces overall system life
- Switching losses: Each switch in the grid-side inverter and the generator-side converter between the upper and lower branch causes losses.
- The high switching speed to the grid may also require additional EMI filters.
- The combined control of the rectifier and the controlled inverter is quite complicated.

Matrix converter

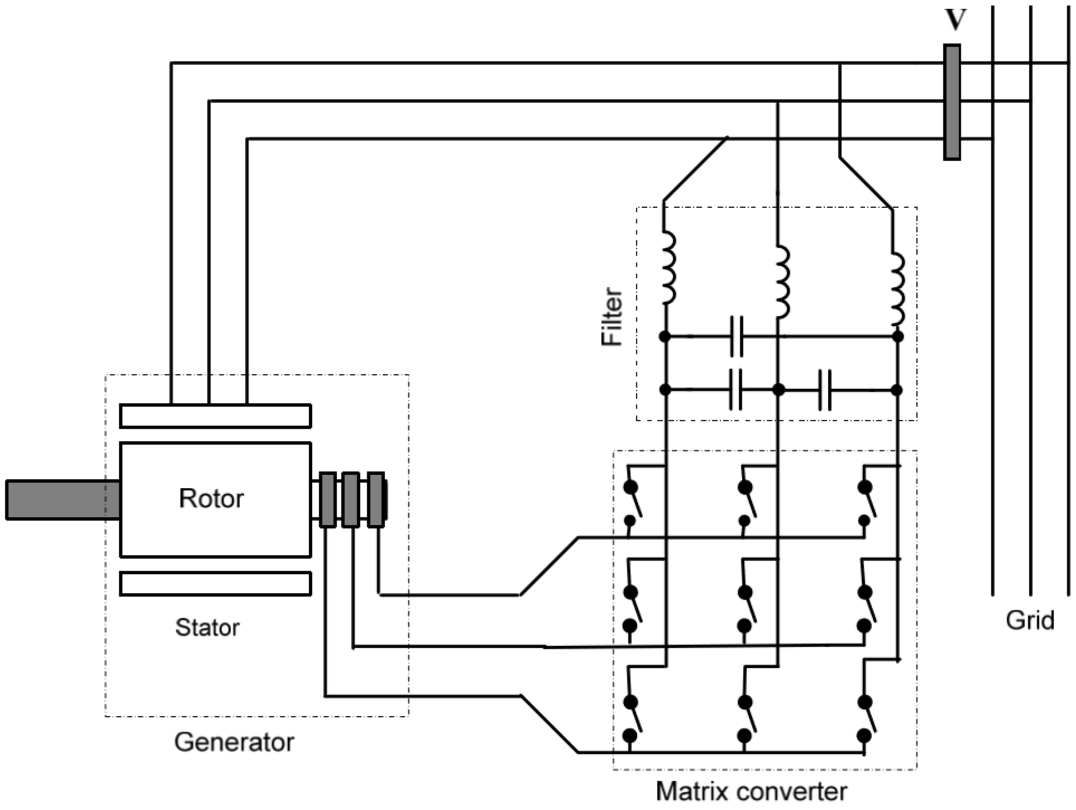
The matrix converter (MC) is a unique topology of the AC to AC power converter that eliminates the need for DC intermediate conversion and the passive reactive filter components associated with this DC link. This is a direct topology or with a single AC to AC conversion step. The converter consists of bidirectional switches positioned at the points of intersection of the input and output phases. The output is synthesized by selective closings and switch openings. A filter on the input side facilitates switching and prevents the harmonics generated by switching from propagating to the power input. MCs offer the possibility of considerably reducing the size and weight of power converters due to the absence of new energy storage elements, such as DC link capacitors. Compared to a conventional back-to-back converter, the MC is much smaller in size.

The THD coefficient of MC is much better than that of ‘back to back’ and diode rectifier based converters.



Wind Generator with Matrix converter

Due to its advantages over the back-to-back converter, the MC is currently replacing the back-to-back converter in DFIG wind turbine generator systems.



DFIG Wind Energy generator with Matrix converter

Benefits:

- Matrix converters offer the potential for significant size and weight reductions in power converter applications due to the absence of large energy storage elements, such as DC-link capacitors.
- Although the matrix converter includes six additional power switches when compared to the back-to-back converter, the absence of the capacitor can increase the efficiency and service life of the converter.
- Depending on the design of the bi-directional switches, the switching losses of the matrix inverter can be lower than that of the back-to-back converter, because half of the switching becomes natural switching.
- They provide practically sinusoidal waveforms of input and output currents with low level of harmonics.
- The thermal stresses of the semiconductors in a matrix converter are lower than those of a conventional converter.
- The matrix converter is suitable for DC to AC energy conversion, which is an attractive solution for the adjustable speed wind generator, especially for the DFIGs.

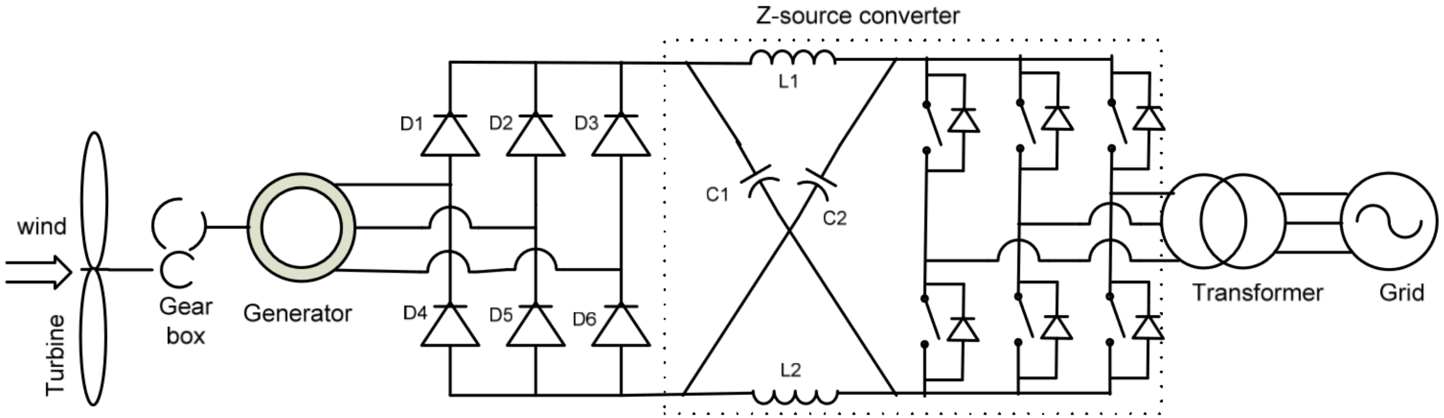
Disadvantages:

- The ad-link DC voltage cannot be increased like that of the back-to-back converter. Without entering the overmodulation range, the maximum output voltage of the matrix converter is 0.866 times the input voltage.
- To obtain the same output power as the back-to-back converter, the output current of the matrix converter must be 1.15 times higher, which results in higher line losses in the converter.
- Due to the absence of the DC link, there is no decoupling between the input and the output of the converter. In ideal terms, this is not a problem, but in the case of unbalanced or distorted input voltages, or unbalanced load, the input current and the output voltage also become distorted.
- The modulation technique and switching control are more complicated than those of the conventional PWM inverter.
- The protection of the matrix converter in a fault situation is not as good as that of the back-to-back converter.

Z-source converter

The impedance source or the energy converter powered by the impedance is abbreviated as Z-source converter. It can be used for implementing DC to DC, AC to DC, AC to AC and DC to AC energy conversions.

In this converter, a two-port network that consists of fractional inductors L1 and L2 and capacitors C1 and C2 connected in X form is used to provide an impedance source coupling the converter to the DC source, the load, or a other converter. The DC source or load can be either a voltage, or a source or current load. Therefore, the DC source can be a battery, a diode rectifier, a thyristor converter, a generator, a



Z-source converter for Wind Energy

Benefits:

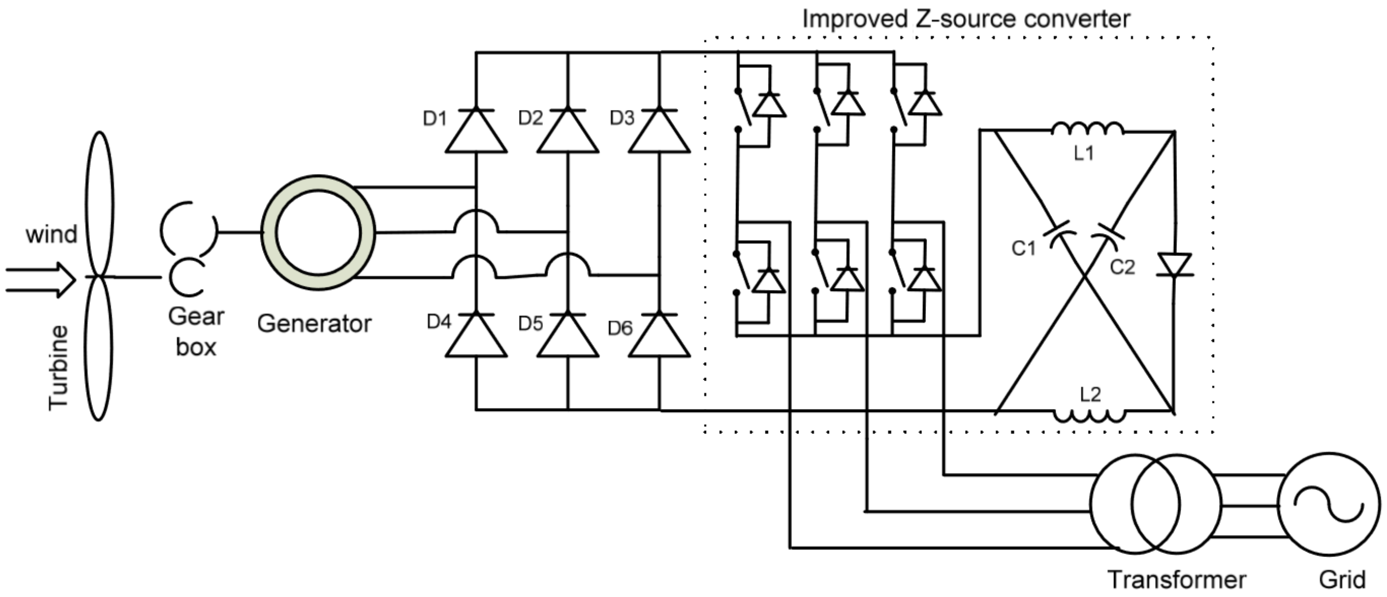
- The output voltage can be any value between zero and infinite (buck and boost) regardless of the input voltage.
- It uses fewer components than conventional converters.
- Because of its ability to manipulate shooting states through its application is more reliable.
- It is cheaper and smaller the conventional converter (inductors and capacitors can be optimally designed).
- More effective than the others.

Disadvantages:

- To perform the voltage boost function for the source Z stage, the voltage of capacitor Z is greater than the input voltage. Thus, high voltage Z capacitors should be used, which can increase the volume and cost.
- The Z-source converter cannot suppress the precipitation current and the resonance between the Z capacitors and the Z inductors at start-up. This causes overvoltages and current surges and can destroy the device.
- It is intrinsically a unidirectional converter.

Improved Z-source converter

This improved z-source converter has all the features, but also overcomes the disadvantages of the Z-source converter. Exactly the same elements are used as in the Z-source converter, but the positions of the bridge and the diode of the converter are exchanged and their connection direction is reversed. Due to the voltage polarity of Z Zacators keeping the same as the input voltage polarity, the voltage stress of Z-capacitor can be greatly reduced and get the same push voltage across the converter bridge. In this system, there is no current path at startup, so it has inherent inrush current limiting ability.



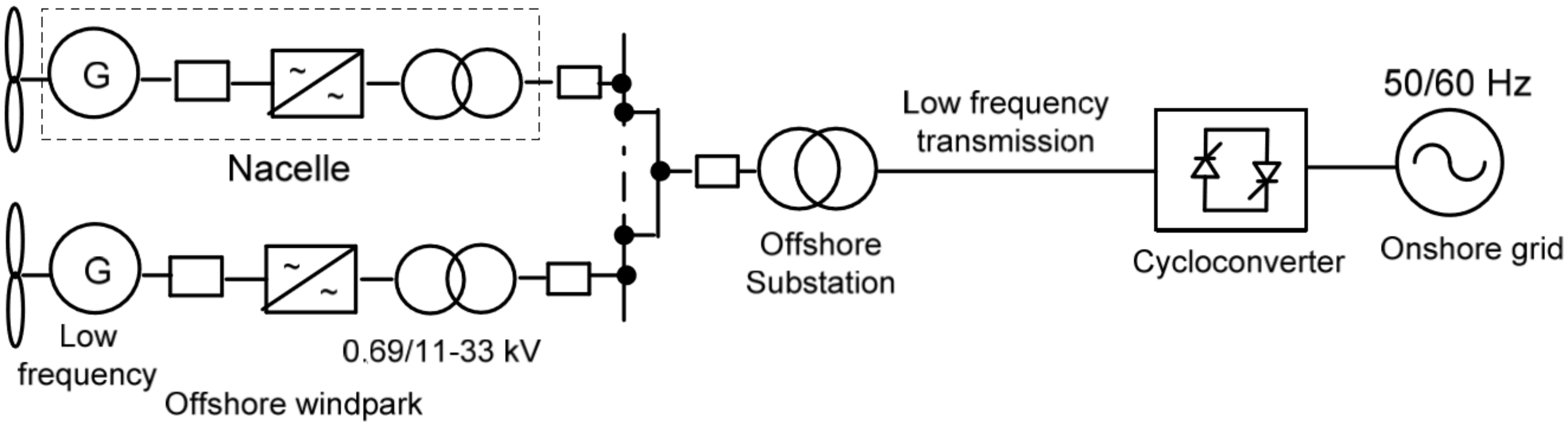
Improved Z-source converter for power generation

Cycloconverter

Like the MC converter, the cycloconverter also converts AC to AC directly without using any DC-link intermediate capacitors. It is also called a frequency converter.

Cycloconverters are used for offshore wind farms because the investment cost of the low frequency transmission network for the offshore wind farm is less expensive than the HVDC system and the maintenance costs are also greatly reduced.

When generators are operated at lower frequencies, the system requires only an increasingly rapid cycloconverter at the end of the transmission line. If the generators operateat 50 Hz or 60 Hz, both ends require frequency converters.



Wind Energy Converter using cycloconverter

Benefits:

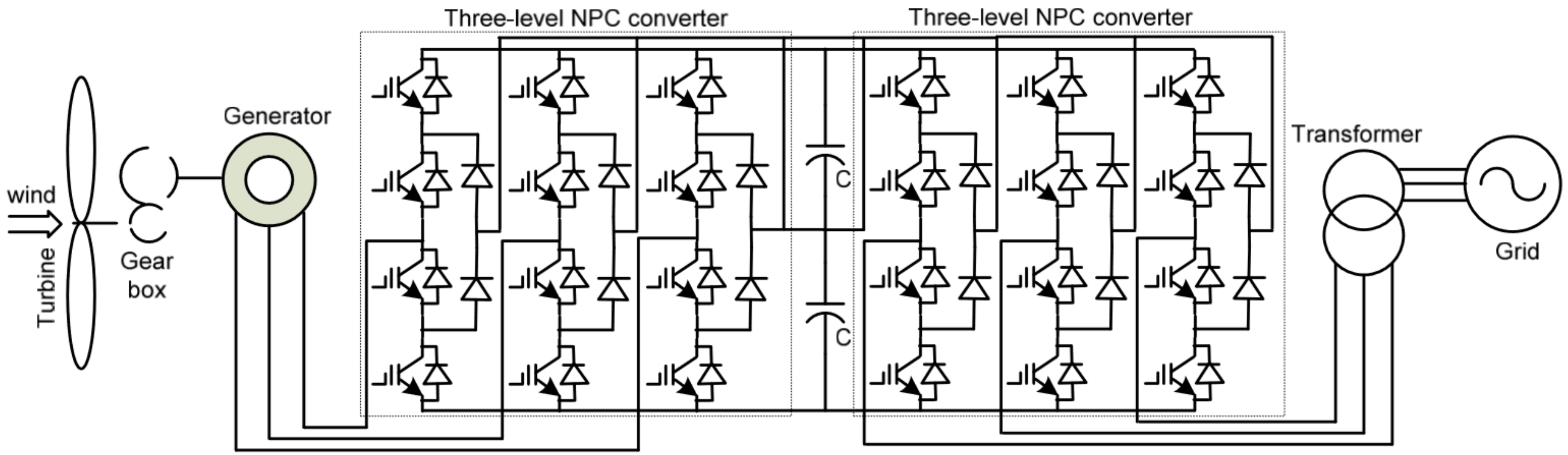
- Reduction of switching and conduction losses
- Bidirectional power flow capacity and
- The design of the power circuit is compact

Disadvantages:

- There is an upper output frequency limit
- Poor input power factor
- Lower voltage transfer rate
- It requires complex control circuits

Multilevel converters

The multi-level converter is an electronic power circuit which can be operated in inverter or rectifier mode.
In order to achieve high voltage using low voltage switching devices, the topology of the multilevel converter uses a series of switching devices with low voltage DC sources. Renewable energy sources: wind turbine generators, photovoltaic solar panels and fuel cells can be used as multiple voltage sources. Appropriate control of switching devices consists of superimposing these multiple DC sources in the form of a staircase in order to reach the high voltage at the output. Currently, there is a growing interest in multi-level power converters, especially for medium voltage applications. The topologies of neutral point converters (NPC), flying capacitor (FC) and H-bridge conversion converters (SCHB) connected in series are the three types of multilevel converters commonly practiced in high power and medium applications / high tension



Neutral point clamped multilevel converter for wind energy

Benefits:

- The main advantage of the multi-level converter is the ability to handle at high voltage.
- Lower switching losses and higher overall efficiency than others.
- Allows a reduction in the size of the filter elements, which affects the dynamic response of the converter.

Disadvantages:

- Requires a number of semiconductor devices, which increases the complexity of the control circuit.
- The voltage imbalance between the upper capacitor and the lower DC bus capacitor.
- Uneven stress on semiconductors.

Conclusions

- The applications of electronic energy for wind turbine technology have been briefly explained.
- The applications of power electronics in various types of wind turbines show that the behavior of the wind turbine / performance is greatly improved.
- Power components are capable of facilitating frequency and voltage control through active and reactive power control.

Bibliographie

[1] ‘Working with Wind, Integrating Wind into the Power System’. IEEE Power and Energy Magazine, 3(6), November/December 2005.

[2] Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R. and D’haeseleer, W., ‘Distributed Generation: Definition, Benefits and Issues’. Energy Policy, 33(6), April 2005, 787–798. ISSN 0301-4215, DOI: 10.1016/j.enpol.2003.10.004.

[3] Lubosny, Z., Wind Turbine Operation in Electric Power Systems Advance Modeling, Berlin–Heidelberg: Springer, 2003, Hardcover, 259 pages. ISBN 3-540-40340-X.

[4] Ackermann, T., Wind Power in Power Systems, John Wiley & Sons, Ltd., 2005. ISBN 0-470-85508-8.

[5] Heier, S., Grid Integration of Wind Energy Conversion Systems, John Wiley & Sons, Ltd, 1998.

[6] Hansen, L.H., Madsen, P.H., Blaabjerg, F., Christensen, H.C., Lindhard, U. and Eskildsen, K., ‘Generators and Power Electronics Technology for Wind Turbines’. In Proceedings of IECON ‘01, Vol.3, 2001, pp. 2000–2005.

[7]Petru,T.andThiringer,T.,‘Modellingofwindturbinesforpowersystemstudies’.IEEETransactionsonPower Systems, 17 (4), November 2002, 1132–1139.

[8] Hansen, L.H., Helle, L., Blaabjerg, F., Ritchie, E., Munk-Nielsen, S., Bindner, H., Sørensen, P. and Bak-Jensen, B., ‘Conceptual Survey of Generators and Power Electronics for Wind Turbines’, 2001, Risø-R-1205 (EN). ISBN 87-550-2745-8.

Thank You for Your Attention!

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Contact: info@weset-project.eu weset.erasmusplus@uva.es

Co-funded by the
Erasmus+ Programme
of the European Union

Mechatronics in Wind conversion process

Module 2.3

Integration of Wind Energy into the power grid
Lesson 3

Co-funded by the
Erasmus+ Programme
of the European Union

Objective

In this part of the course we will discuss the issues arising when integrating wind energy into the power grid, and the solutions.

Co-funded by the
Erasmus+ Programme
of the European Union

Learning Outcomes

At the end of this lesson the students will be able to :

- *Understand the issues arising in the connection of wind turbines to the network grid.*
- *Appreciate the development of design needs and innovation in the international market.*
- *Present, discuss and argue grid connection technologies.*

Co-funded by the Erasmus+ Programme of the European Union

Technical Contents

1) Introduction : The connection of a wind turbine (WT) to the grid
2) WTS Power configurations
3) Grid Power Converter Topologies

Co-funded by the
Erasmus+ Programme
of the European Union

Introduction

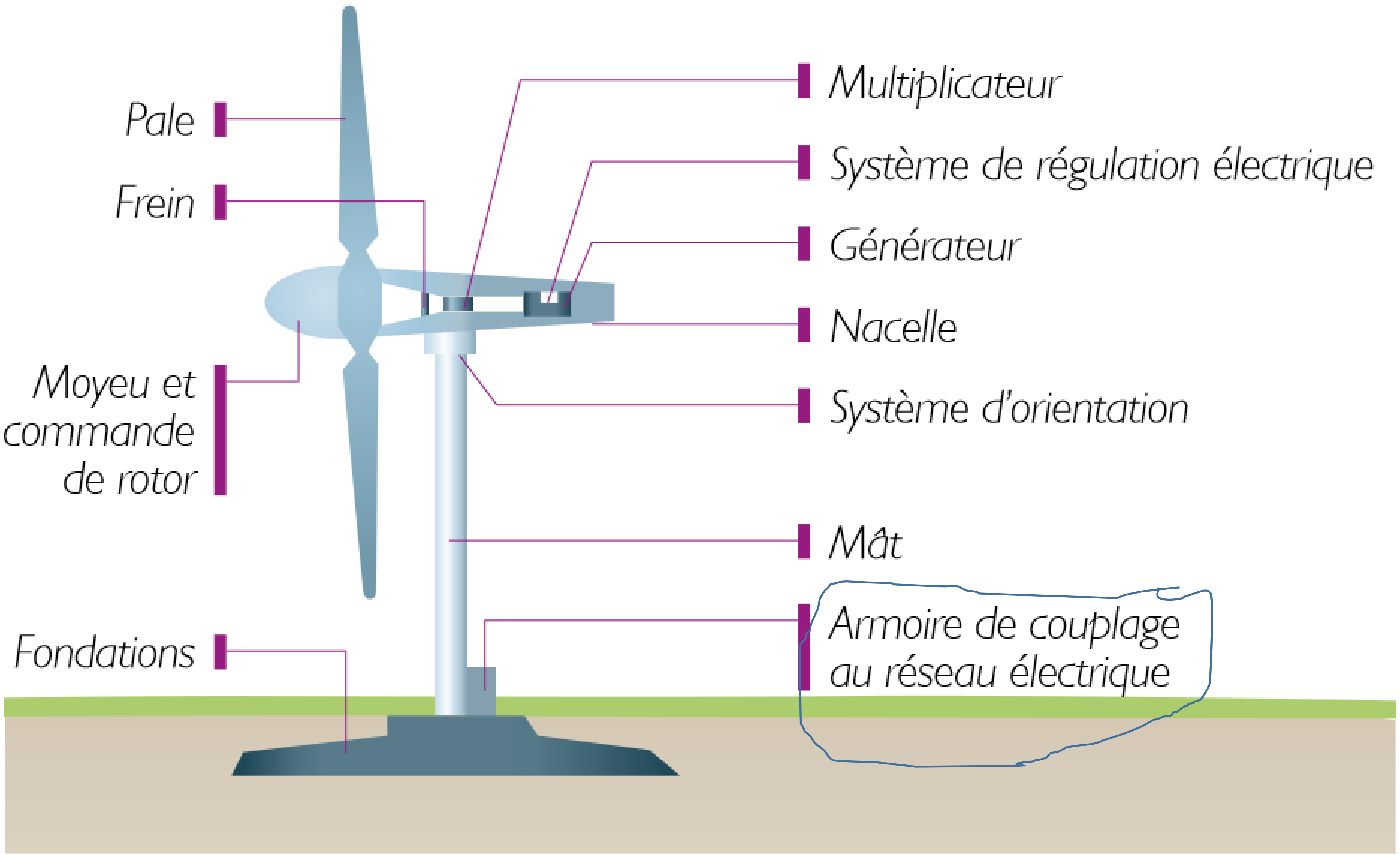
- The Electric System = matching production supply with consumption demand across a network.

- The demand is variable, even if it is foreseeable, there remains a stochastic aspect.

- To cope with the uncertainty of demand, the means of production must be controllable: control of the energy injected, supply of production program, rapid upward or downward modulation, ...

- Wind production is variable, inflexible (stop / start) and provides uncertain production programs.

- Wind production is not programmable and represents an additional hazard in the system



Wind Generator

What are the problems to solve?

- **Connection to the network (reception capacity, voltage quality, ...)**

- **_ The functioning of the electrical electrical system (resistance to faults, participation in system services, reserve, ...)**

- **Electricity markets (planning of insertion of renewable energy, D-1 market, adjustment, ...)**

What are the solutions for large-scale integration?

The solutions depend on the wind technology

Wind Energy Technology

Growing Power

Fixed speed wind turbines

Variable speed wind turbines

- Asynchronous cage machine
- Synchronous machine with wound rotor
- Synchronous permanent magnet machine
- Double feed machine

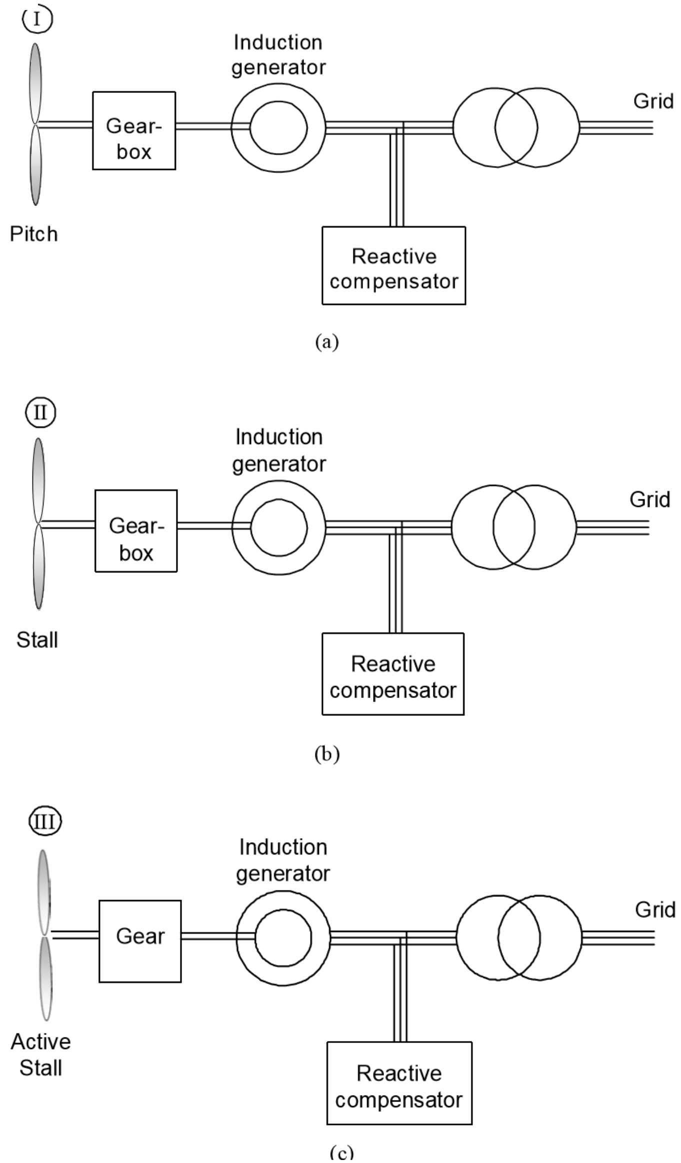
FIXED-SPEED WIND TURBINES

FIXED SPEED WIND TURBINES

The conversion of wind energy into mechanical power is done aerodynamically. It is important to be able to control and limit the mechanical power converted to a higher wind speed, because the power in the wind is a cube of the wind speed. The power limitation can be carried out either by the stall control (the position of the blade is fixed, but the wind stall appears along the blade at a higher wind speed), active stall (the angle of the blade is adjusted to create stall along the blades) or height control (the blades are oriented out of the wind at a higher wind speed).

Wind turbine technology can basically be divided into three categories:

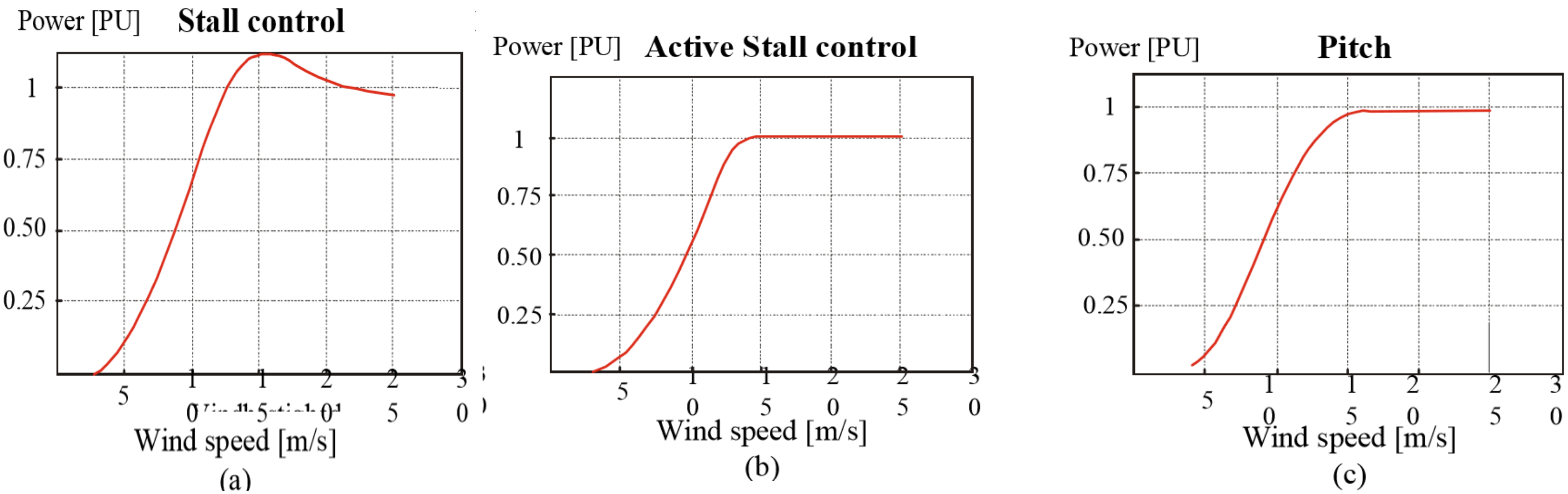
1. systems without power electronics,
2. wind turbines with partially rated power electronics (small PE converter)
3. large-scale electronic power of interface wind systems (large PE converter).



Wind turbine systems without power converter but with aerodynamic power control.

a) Controlled pitch (System I)
b) Controlled stall (System II)
c) Active controlled stall (System III)

Wind turbine systems use induction generators, which operate almost independently of the variation of the torque at a fixed speed (variation of 1 to 2%). The power is aerodynamically limited either by stall, active stall or by pitch control. All three systems use a soft starter to reduce the current of inrush and thus limit flicker problems on the grid. They also need a reactive energy compensator to reduce (almost eliminate) the demand for reactive energy from turbine generators to the grid. It is generally done by continuously changing the capacitor banks according to the production variation (5-25 steps). These solutions are attractive because of the cost and reliability but they are not able very fast (within a few ms) to control the active power. In addition, gusts of wind can cause torque pulsations in the oil drain and significantly load the gearbox.



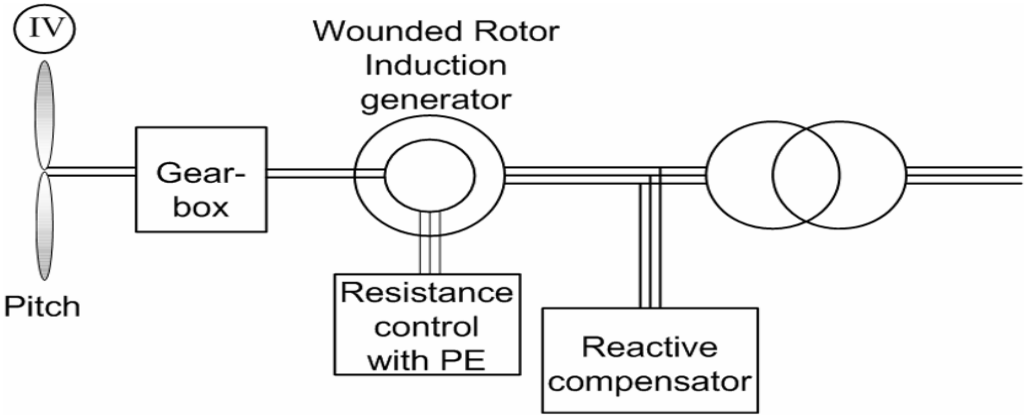
The basic power characteristics of the three different fixed speed concepts

a) Stall control b) Active stall control c) Pitch control

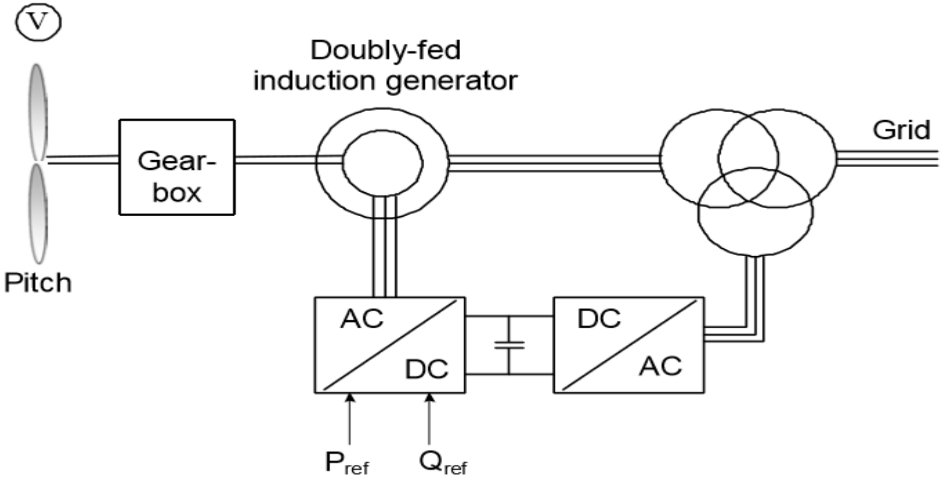
By turning the blades either by pitching or active stall control, it is possible to limit the power precisely while the power measured for the turbine controlled by stall shows a small go-around. It depends a lot on the final aerodynamic design.

VARIABLE SPEED WIND TURBINES

The next category is wind turbines with partially evaluated energy converters and thereby improved control performance can be obtained:



(a)



(b)

Wind turbine topologies with partially rated power electronics and limited speed range. a) Rotor resistance converter (system IV) b) Double-powered induction generator (system V)

Wind turbine system where the generator is an induction generator with a wound rotor. Additional resistance is added in the rotor, which can be controlled by the power electronics. It is a dynamic slip controller and generally gives a speed range of 2 - 5%. The power converter for rotor resistance control is for low voltage but high currents. At the same time, additional freedom of control is obtained at higher wind speeds in order to keep the output power fixed. This solution still needs a soft starter and a reactive power compensator, which is in continuous operation.

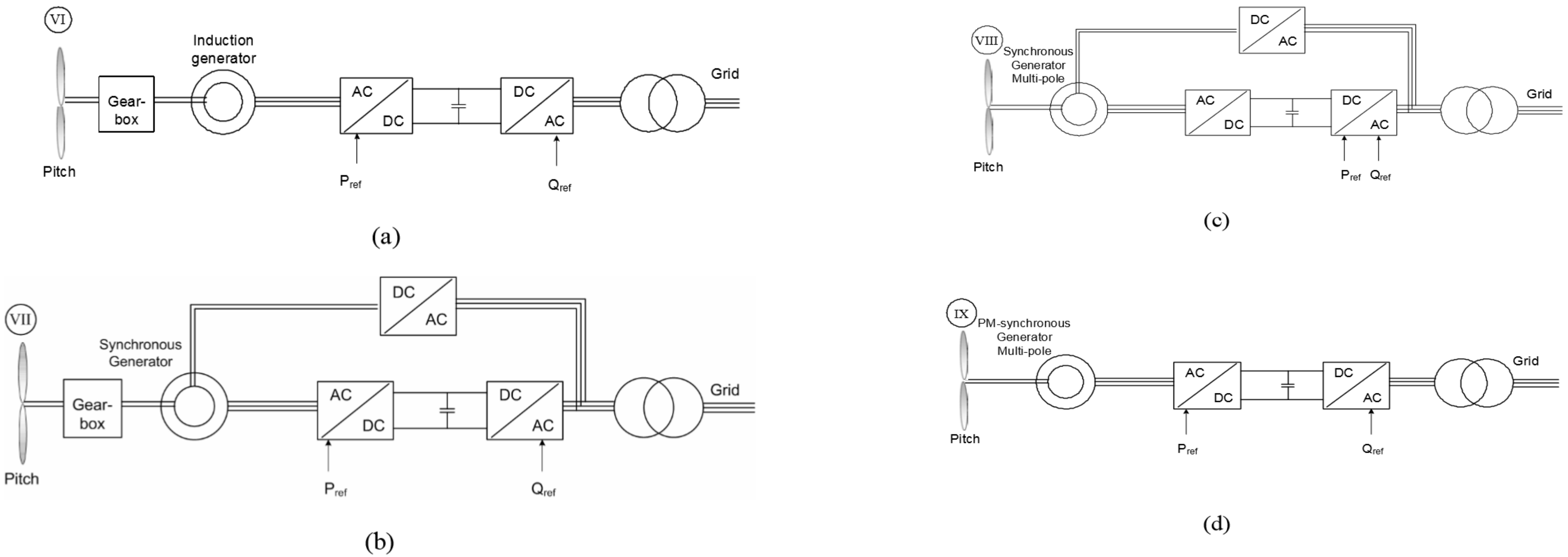
A second solution for using a medium-scale power converter with an injured rotor induction generator is shown b. The sliding rings make the electrical connection to the rotor. A power converter monitors the rotor currents.

If the generator operates in a super synchronous manner, the power supply is supplied by both the rotor and the stator.

If the generator operates sub-synchronously, the power supply is only delivered to the rotor from the network. A speed variation of 30% around the synchronous speed can be obtained by using a power converter with 30% of nominal power.

In addition, it is possible to control both active (Pref) and reactive power (Qref), which gives better network performance, and power electronics allow the wind turbine to act as a source of energy. more dynamic energy for the network. The latter requires neither a soft starter nor a reactive power compensator. The solution is naturally a little more expensive compared to conventional solutions However, it is possible to save money on the safety margin of the equipment, the reactive power compensation units as well as it is possible to capture more wind energy

The third category is wind turbines with a large-scale energy converter between the generator and the grid, which are the ultimate solutions technically. It gives additional losses in power conversion, but it can be gained by additional technical performance. Four possible, but not exhaustive, solutions with full-size power converters:



Wind turbine systems with full-scale power converters. a) Induction generator with gear (System VI) b) Synchronous generator with gear (System VII) c) Multi-pole synchronous generator (System VIII) d) Multi-pole permanent magnet synchronous generator (System IX)

The solutions indicated in a) and b) are characterized by a gear. A synchronous generator solution shown in b needs a small power converter for field excitation.

Multi-pole systems with the synchronous generator without gears are indicated in c) and d).

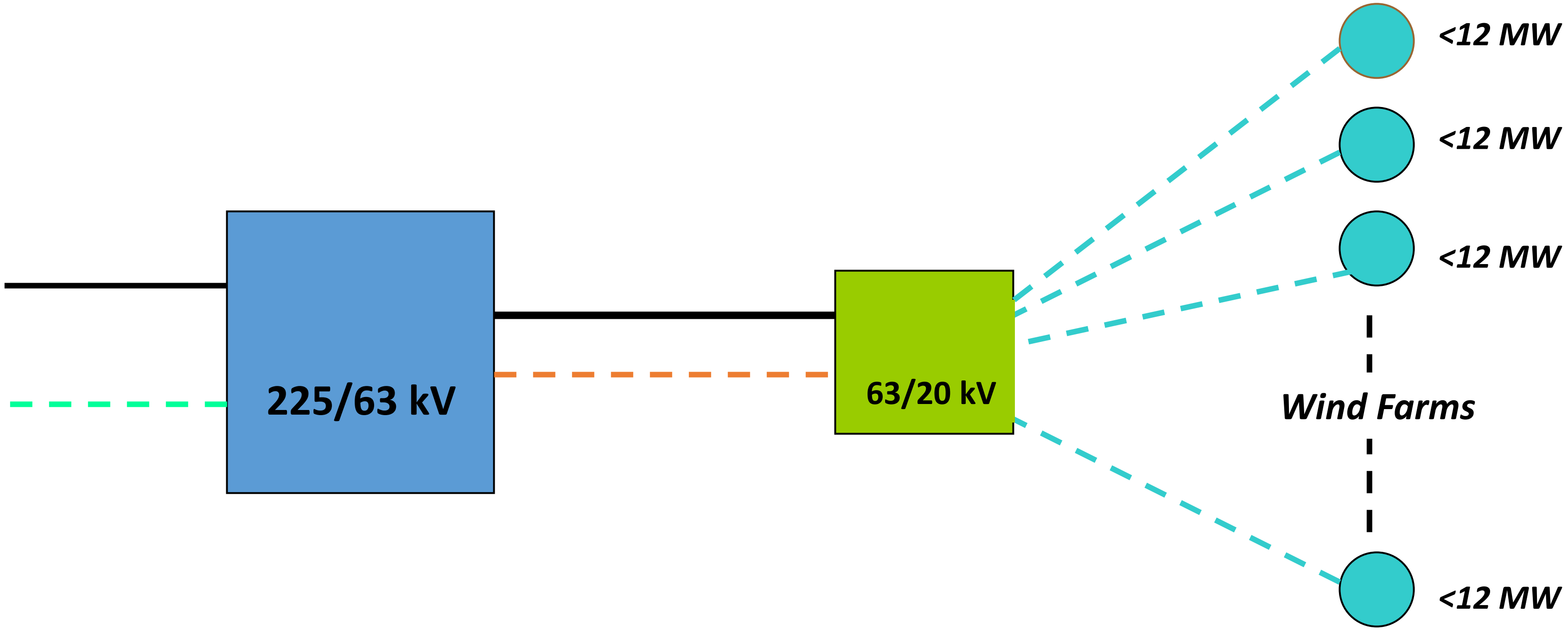
The last solution is to use permanent magnets, which are still less and less expensive and therefore more attractive. The four solutions have the same controllable characteristics since the generator is decoupled from the network by a DC link.

The grid power converter allows the system to control active and reactive power very quickly. However, the negative side is a more complex system with more sensitive electronic parts

System comparison of wind turbines									
System	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Variable speed	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Control active power	Limited	No	Limited	Limited	Yes	Yes	Yes	Yes	Yes
Control reactive power	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Short circuit (fault-active)	No	No	No	No	No/Yes	Yes	Yes	Yes	Yes
Short circuit power	contribute	contribute	contribute	contribute	contribute	limit	limit	limit	limit
Control bandwidth	1-10 s	1-10 s	1-10 s	100 ms	1 ms	0.5-1 ms	0.5-1 ms	0.5-1 ms	0.5-1 ms
Standby function	No	No	No	No	Yes +	Yes ++	Yes ++	Yes ++	Yes ++
Flicker (sensitive)	Yes	Yes	Yes	Yes	No	No	No	No	No
Softstarter needed	Yes	Yes	Yes	Yes	No	No	No	No	No
Rolling capacity on grid	Yes, partly	No	Yes, partly	Yes, partly	Yes	Yes	Yes	Yes	Yes
Reactive compensator (C)	Yes	Yes	Yes	Yes	No	No	No	No	No
Island operation	No	No	No	No	Yes/No	Yes/No	Yes/No	Yes/No	Yes
Investment	++	++	++	++	+	0	0	0	0
Maintenance	++	++	++	++	0	+	+	+	+

N.B Over 75% of all wind turbines sold are controlled by power electronics.

Schematic of integration into power grid



Grid operation

The network operator must ensure:

- production / consumption balance

- respect for transit in lines: dispatching;

- the quality of the electric wave.

Connection of wind turbines and overall effects

Global effects:

- frequency adjustment problem
- network planning problem

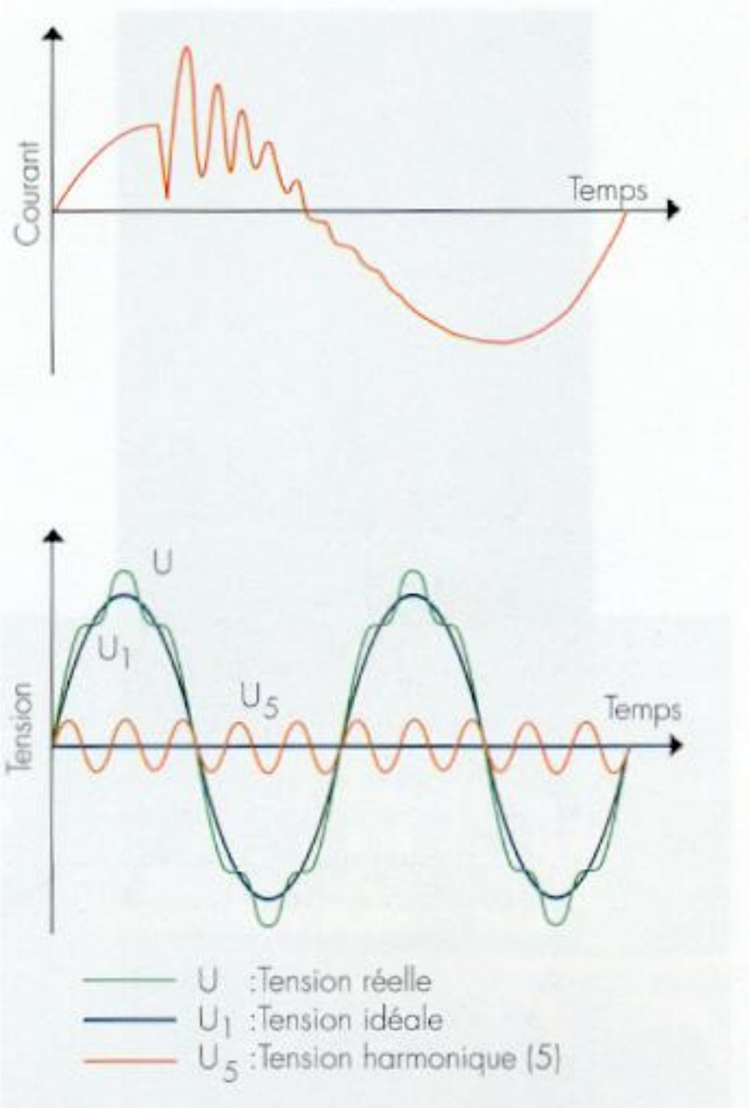
Local effects:

- voltage adjustment
- Use of technologies capable of regulating the voltage

Connection of wind turbines

<u>Voltage quality</u>

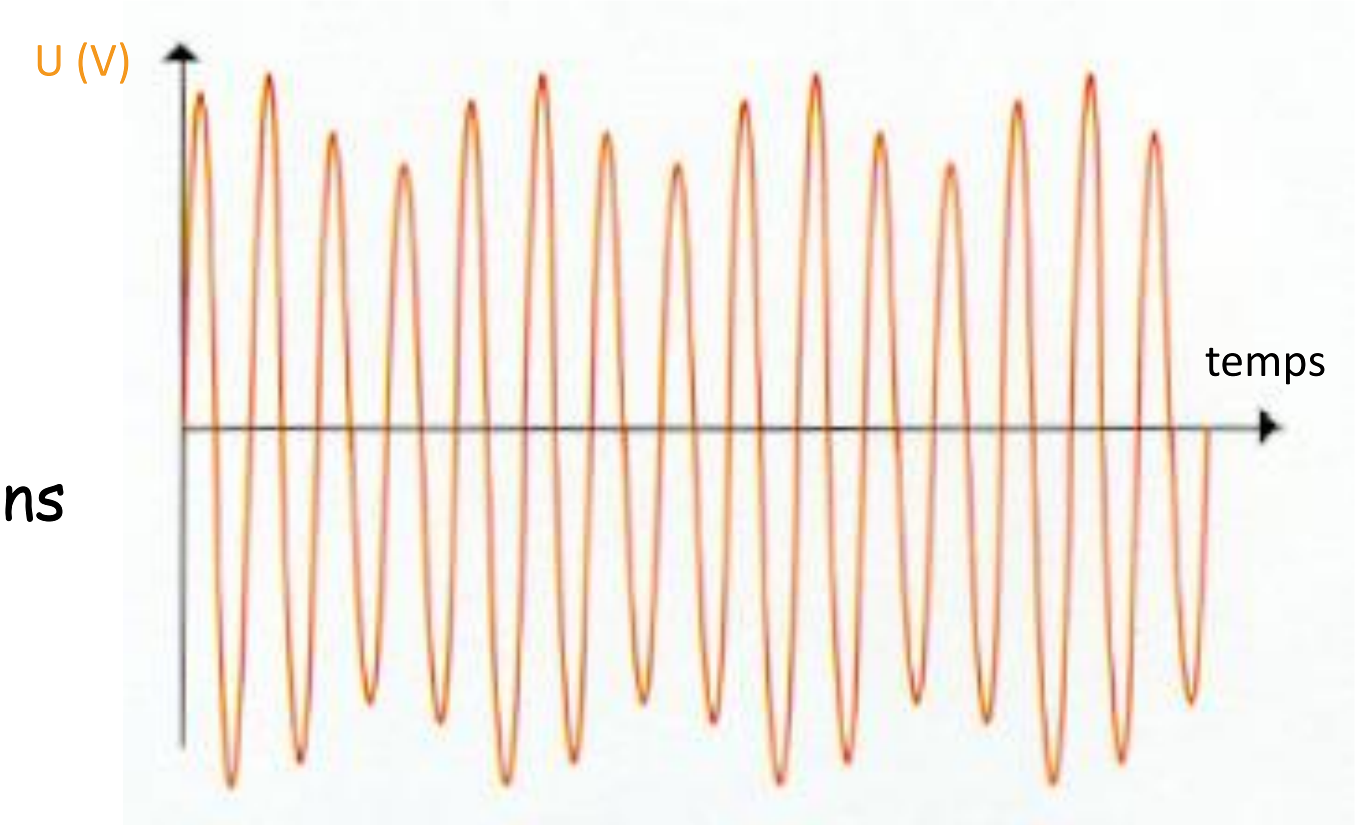
- Resistance to short cuts: disconnection of the machine
- Harmonics: distort the wave



Connection of wind turbines

<u>Voltage quality</u>

- Flicker: caused by periodic variations in the wind



Which connection type?

All these problems mentioned have solutions, but they are costly

➬ Adopt a pragmatic approach: network reception capacity (without reinforcement): 5000MW

Solutions may appear in the short term:

- planning of the connection of wind turbines;
- power electronics.

5000MW threshold may increase

Which connection type?

When short-term leads are exhausted, development of the wind industry conditioned by the emergence of certain solutions:

- forecasting tools;

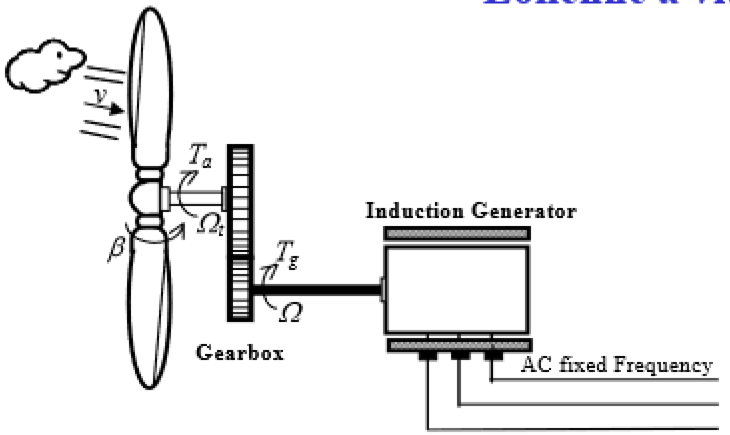
- energy storage

Raccordement : Flicker

- Variation rapide de la tension

- Dépend de la technologie de l'éolienne

Eolienne à vitesse fixe

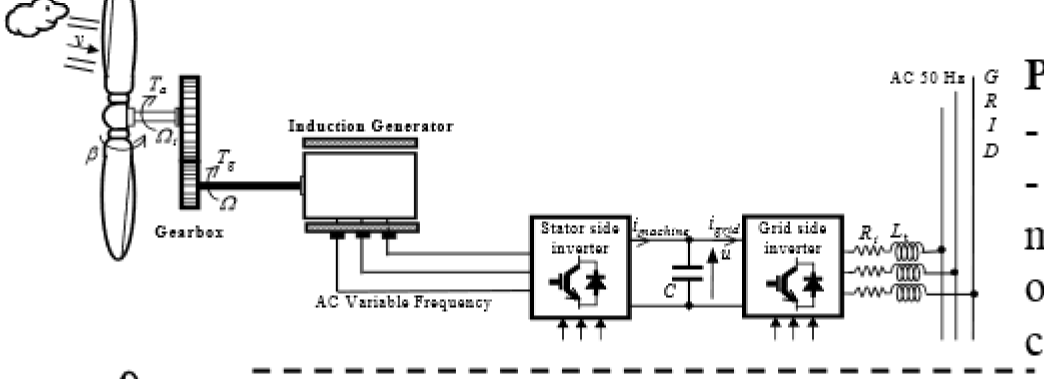


Transfert direct des variations de puissance aérodynamique sur le réseau

$$J\frac{d\Omega}{dt} = c_{electromecanique} - c_{pertes}$$

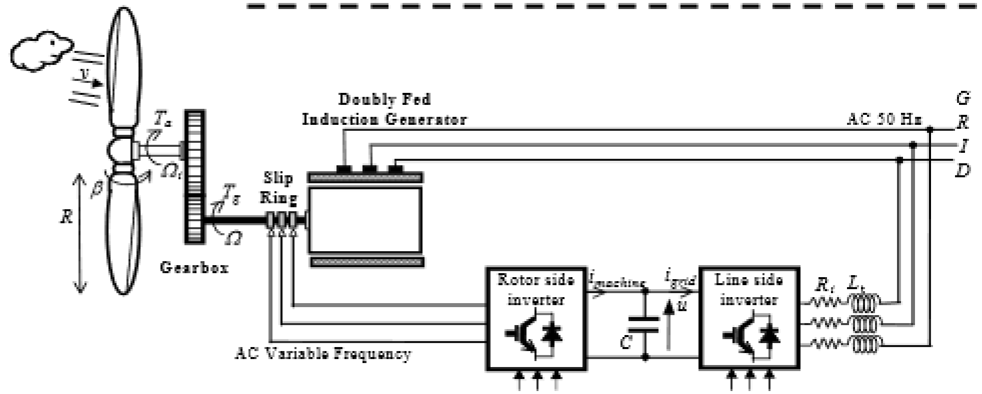
Raccordement : Exemple du flicker

Eoliennes à vitesse variable



Pas de transfert si

- Variation du bus continu
- contrôle de la puissance moyenne (≠MPPT), orientation des pales et contrôle de la machine



Pas de transfert si

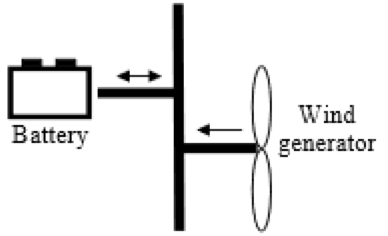
- Régulation de la tension
- Fonctionnement du convertisseur réseau en D statcom

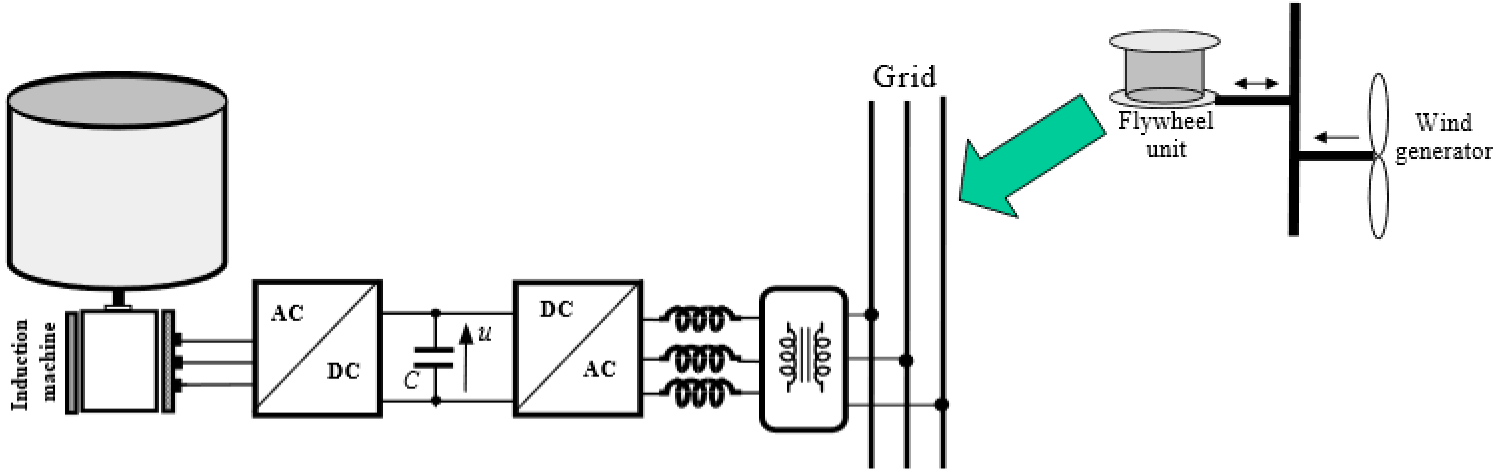
Le système de contrôle a une grande influence sur les variations rapides de tension!

Raccordement : Flicker

- **Solutions**

  Stockage pour compenser les transitoires de puissance :
  - Batteries (vieillissement)
  - Volant d'inertie





- **Deux avantages :**
  - Contrôle rapide de la tension
  - Regulation de la loi statique : Frequence/Puissance

20

Raccordement : Plan de protection

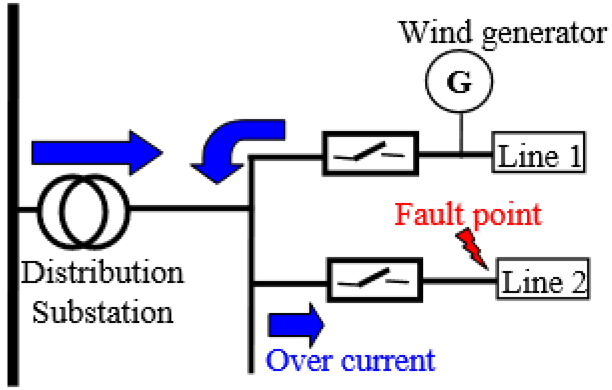
- Les réseaux de distribution sont concus pour un transfert de la puissance électrique du réseau de transport vers les charges

- **Influence** en terme de qualité de protection et de sécurité

- Un impact important : Augmentation du courant de court circuit
- Exemple :

  Le courant lors d’un défaut est fourni à la fois par le réseaux de transport et l’éolienne.

  Si le courant venant du réseau de transport diminue, la protection ne déclenchera pas et le défaut ne sera pas détecté et persistera car toujours alimenté par l’éolienne !

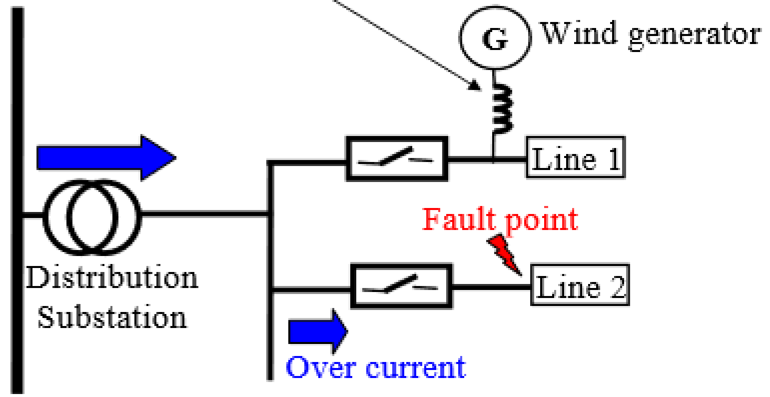


21

Plan de protection

- Systemes de protection particuliers: Negative phase relay, Ground over-voltage relay

- Solutions **externes :** Selfs qui saturent pour réduire le courant de défaut



- **Remarques**

Avec les éoliennes à vitesse variable et donc des convertisseurs electroniques de puissance, l'impact est réduit car la commande contrôle les courants générés et donc les limitent à leur valur maximale !

Fonctionnement du système

- Le taux de pénétration de l'éolien semble limité à 20%
  Genérateur passif

- Pour faire face à la variabilité, 2 objectifs:
  _ Utiliser les éoliennes pour augmenter des possibilités de gestion du réseau électrique
  _ Les faire participer aux services système

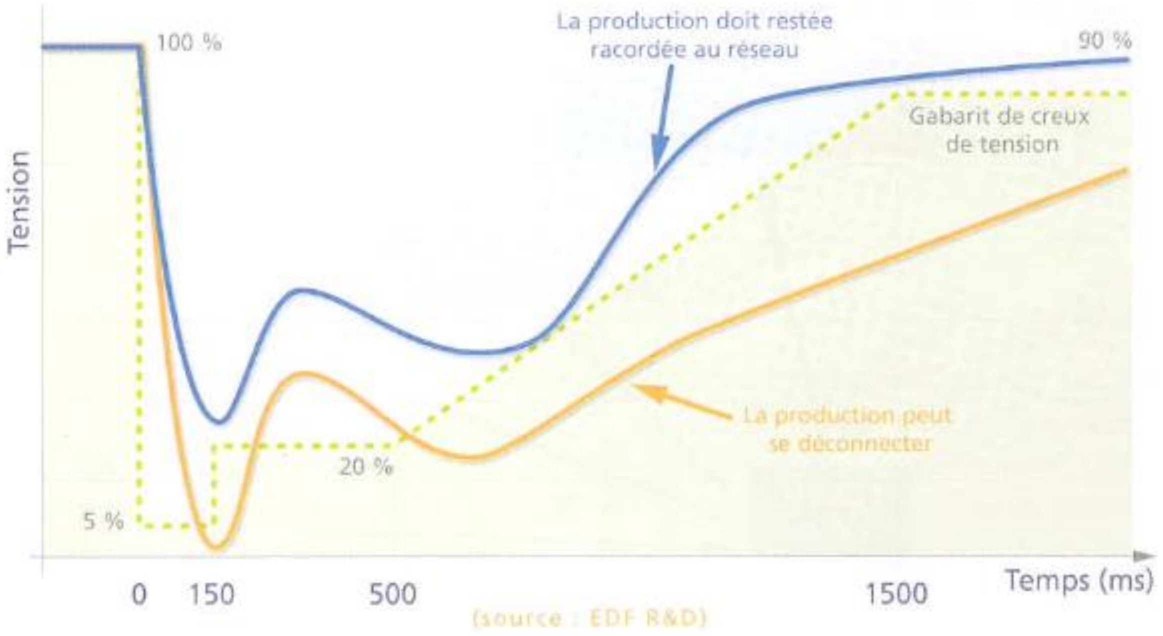
- Techniquement :
  _ Le comportement sur défauts
  _ Les besoins additionnels en réserve
  _ La participation aux services systèmes
    Réglage de la tension
    Réglage de la fréquence

Comportement sur défaut de tension

- Si l'éolien représente une petite part de production, pas de problème, les éoliennes peuvent se déconnecter en cas de défauts provenant du réseau (sur la tension)

- Ce n'est plus possible en Europe car cela entrainerait une perte instantanée de production supérieure (à l'incident dimensionnant la réserve primaire : 3 000 MW)

- Depuis 2000,
  _ Tenue aux défauts à travers la mise en place de gabarit de tenue aux creux de tension
  _ Définition de plages de fréquences admissibles

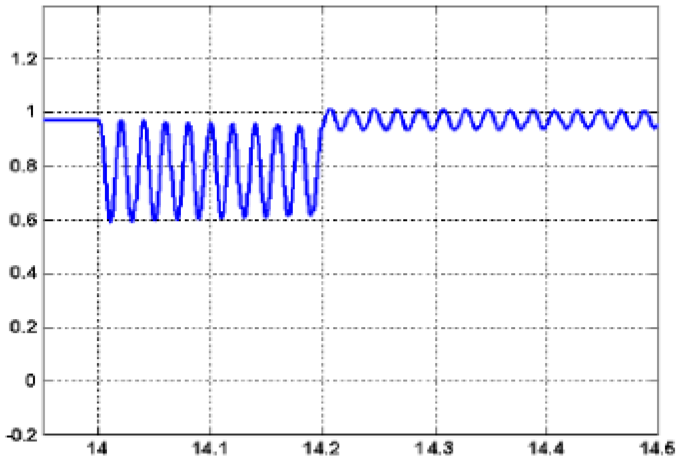


24

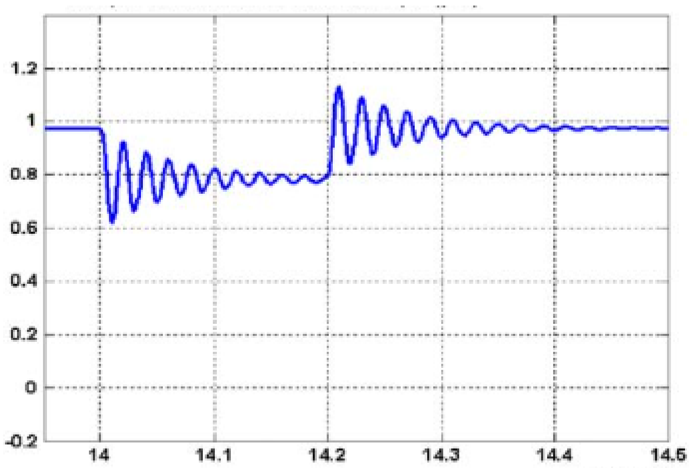
Comportement sur défaut de tension

- Grace à l'électronique de puissance et au contrôle des puissances actives et réactives pendant le défaut, les technologies éoliennes permettent de tenir ces défauts

- Exemple : Amélioration de la stabilité des courants générés par une éolienne à base de MADA par contrôle du flux statorique



(a) Synchronous approach



(b) Asynchronous approach

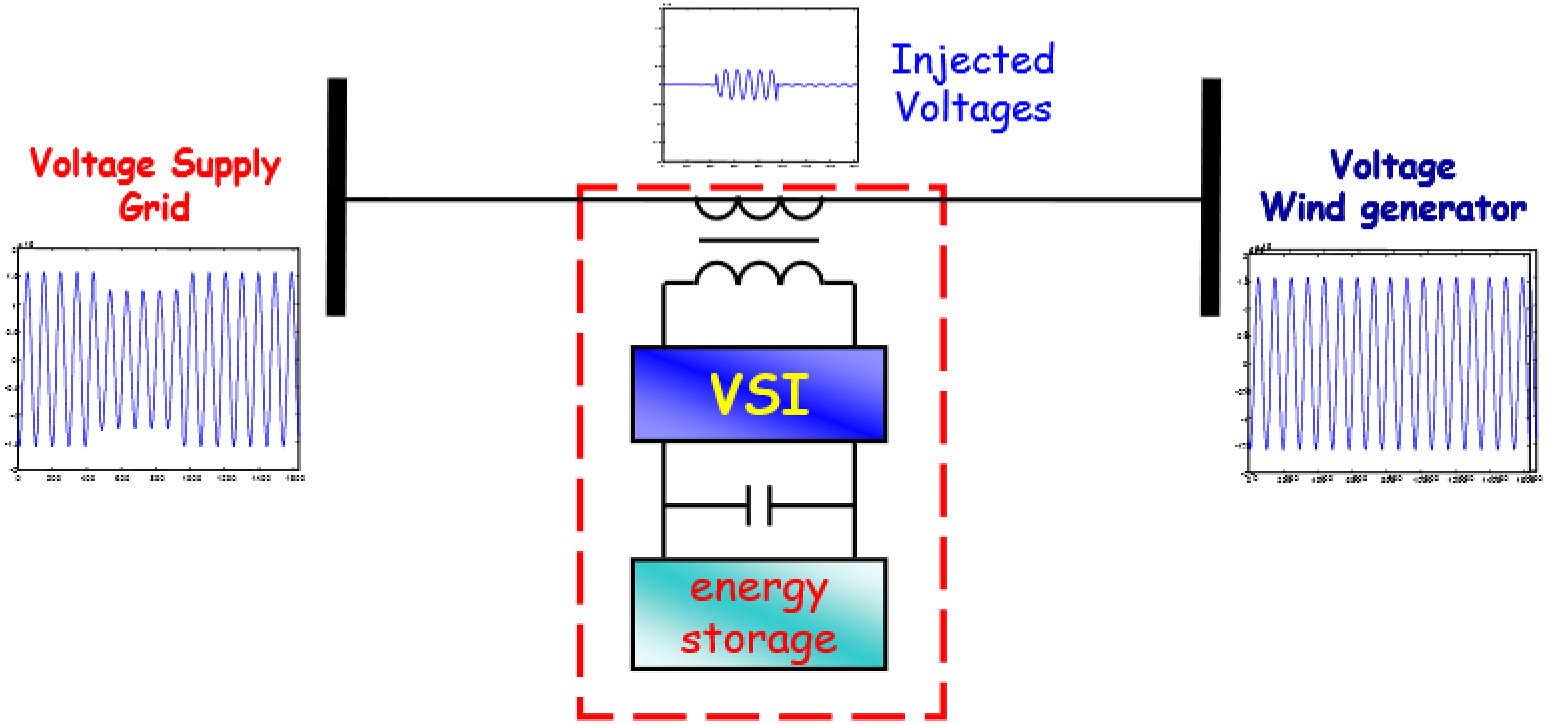
Timing evolution of the stator flux [ELA 05]

25

Comportement sur défaut de tension

- **External solutions**

Dynamic Voltage Restorer



26

[AWA 04]

Conclusions

Solutions for integrating wind into the system

Forecasting and driving system

A few hours, error of 3 to 5% of the installed power

• D-1, error of 5% of the installed power

•> 4D, error> 7.5% of the installed power

Interest, recalculate reserve margins

New sources of flexibility

1. 1.Coupling with other means of production look for complementarities in across markets (economic)
2. 2.Storage

New dedicated network architectures

1. Cluster micro network
2. Continuous urban network (eco-district)
3. Offshore high voltage continuous network

References

- S. Heier. Grid integration of wind energy conversion systems. 2nd Ed. John Wiley & Sons: W. Sussex, England, 2006. ISBN:0470868996.

- Wind power in power systems. (Ed.) T. Ackermann. John Wiley & Sons: W. Sussex, England, 2006. ISBN: 9780470855089.

- J. D. Glover, M. S. Sarma, T. J. Overbye. Power system analysis and design. 5th Ed., CL Engineering, 2012. (ISBN: 1111425779)

Thank You for Your Attention!

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Contact: info@weset-project.eu weset.erasmusplus@uva.es

Co-funded by the Erasmus+ Programme of the European Union