FEDERAL UNIVERSITY OF SANTA CATARINA

Offshore Wind System Conversion System: Models, Operation Modes and Brazilian Scenario

Presenter: Telles Brunelli Lazzarin

November 2024

INEP

Agenda

1. Power Electronics Institute;
2. Wind System – Overview;
3. Wind System – Projects;
4. Project details in partnership with Petrobras;
5. Project details in partnership with CNPq;

POWER ELECTRONICS INSTITUTE - (INEP)

Power Electronics Institute - INEP

1979 → **1994** → **Today**

1979: Founded as LAMEP by Prof. Ivo Barbi

1994: Re-structured as INEP

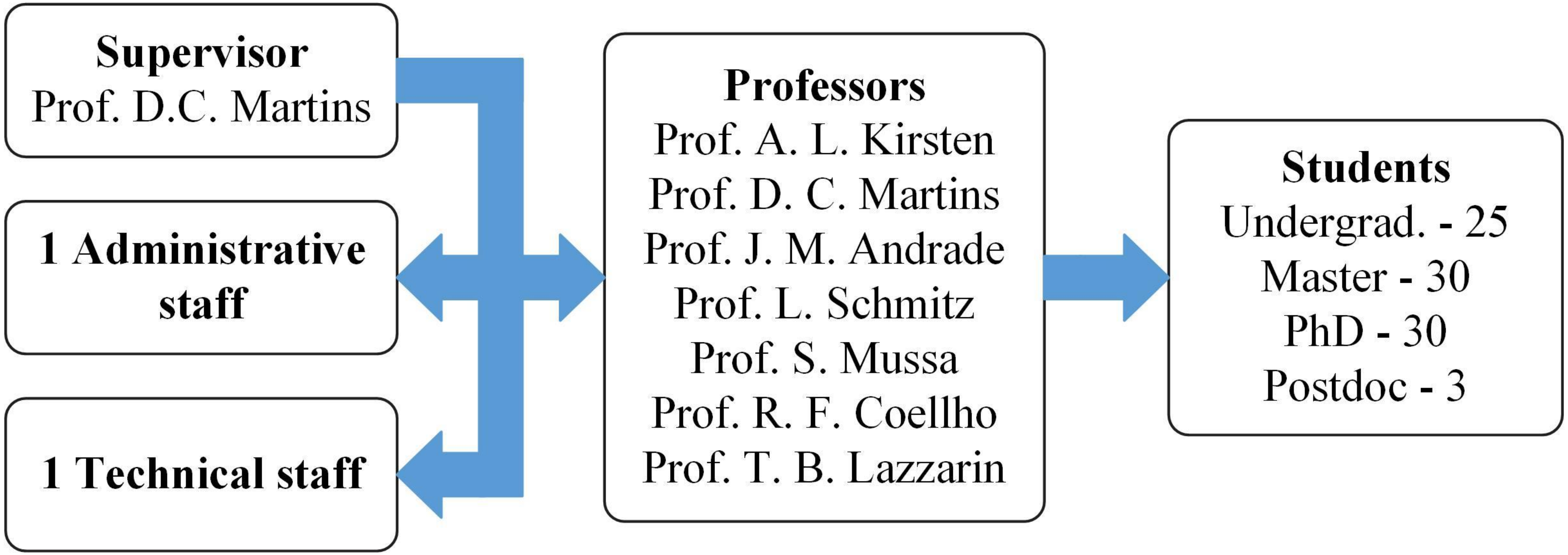
Today: INEP

Since 1979:

- Has been a research center for Power Electronics in Brazil and around the world.
- Many researchers and professors were trained here.

INEP - Team

- INEP in 2024:



INEP - Professors

Prof. D. C. Martins

Prof. L. Schmitz

Prof. S. A. Mussa

Prof. G. Waltrich

Prof. J. M. de Andrade

Prof. R. F. Coelho

Prof. T. B. Lazzarin

Prof. A. L Kirsten

UFSC

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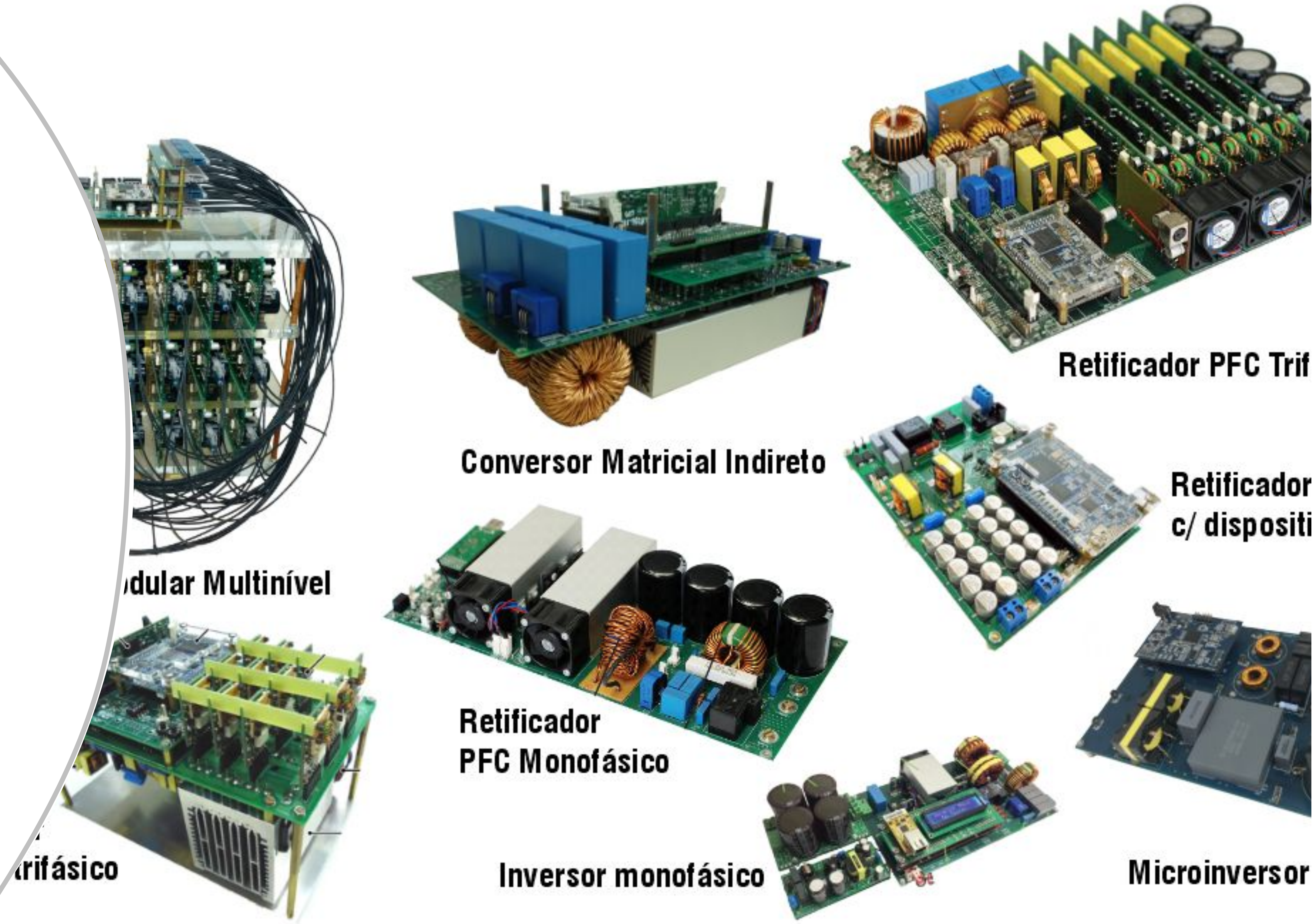
Power Electronics Institute - INEP

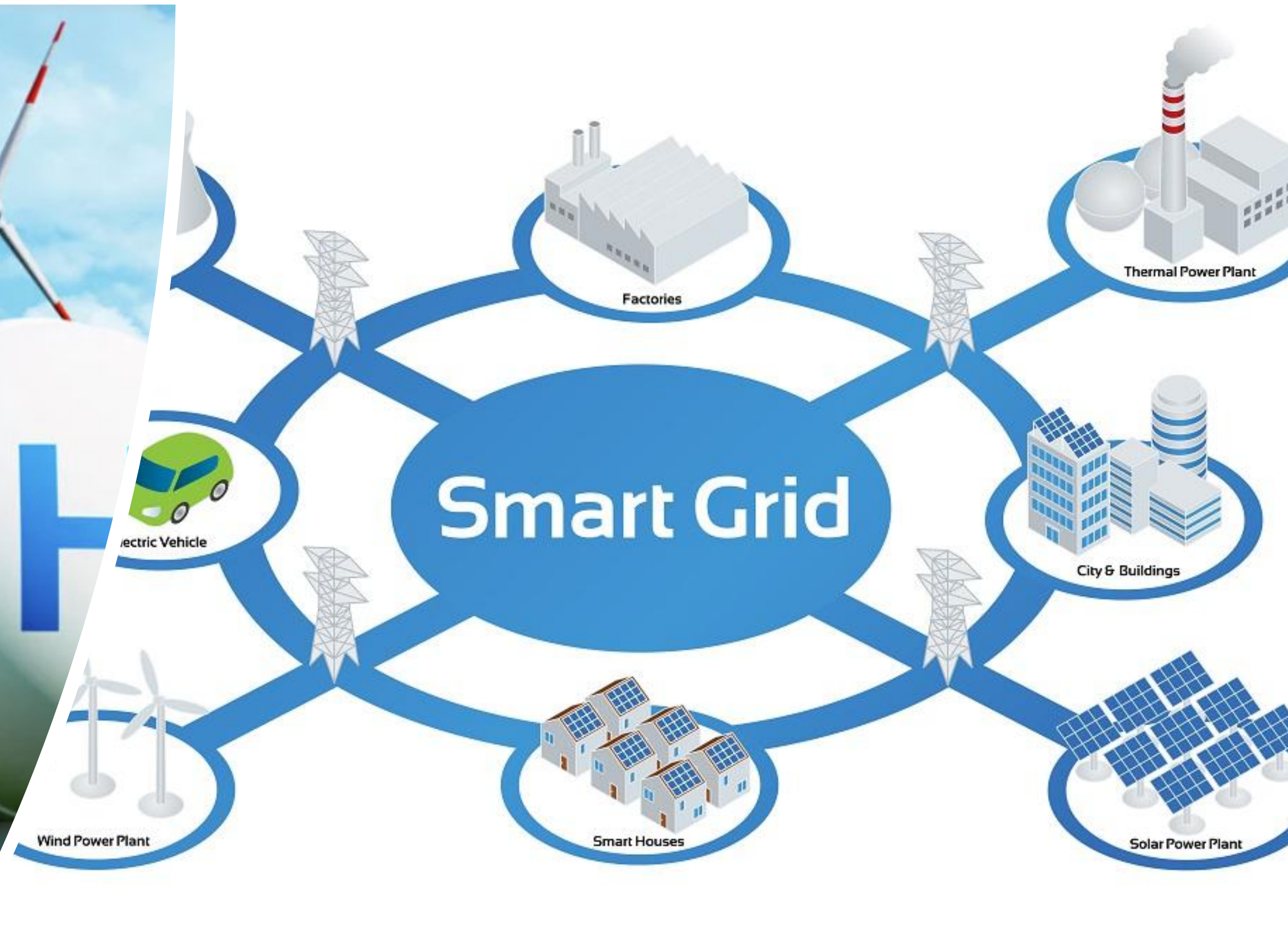
Expertises

- Converters:
  - ❑ New topologies
  - ❑ Modeling
  - ❑ Control strategy
  - ❑ Switching
  - ❑ Modulation
  - ❑ High efficiency



Expertises

- Power Electronic Applications:
  - ❑ Renewable Energies
  - ❑ Distributed Generation Systems
  - ❑ Energy Storage Systems
  - ❑ Electric Vehicles and Infraestructures
  - ❑ Motor drives
  - ❑ Consumer electronics
  - ❑ Data Center



Power Electronic Applications

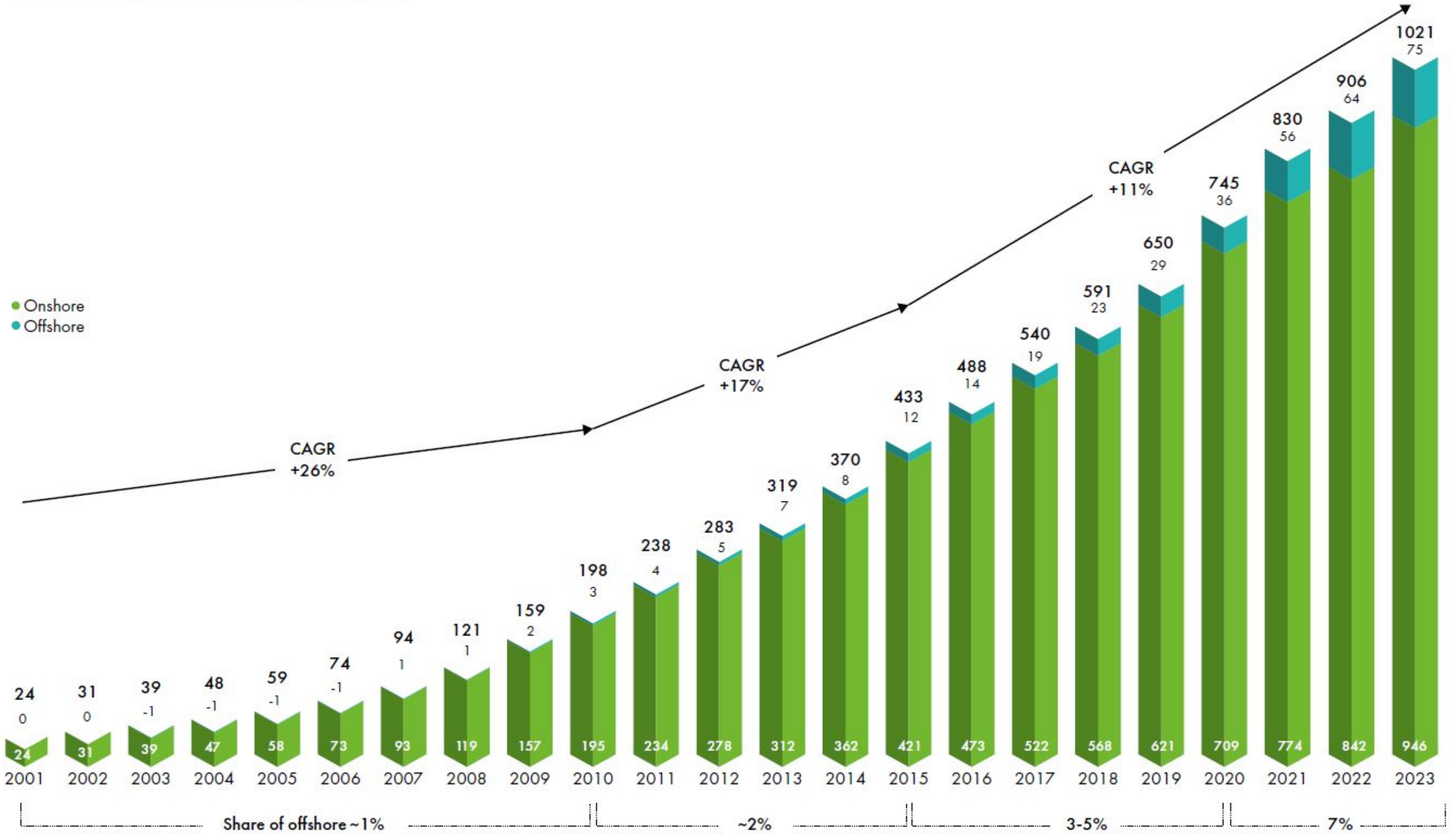
- Offshore Wind Energy Conversion System:
  - ❑ Models
  - ❑ Simulation
  - ❑ Operation Modes
  - ❑ Challenges
  - ❑ Brazilian Scenario
  - ❑ Projects




WIND SYSTEM - OVERVIEW

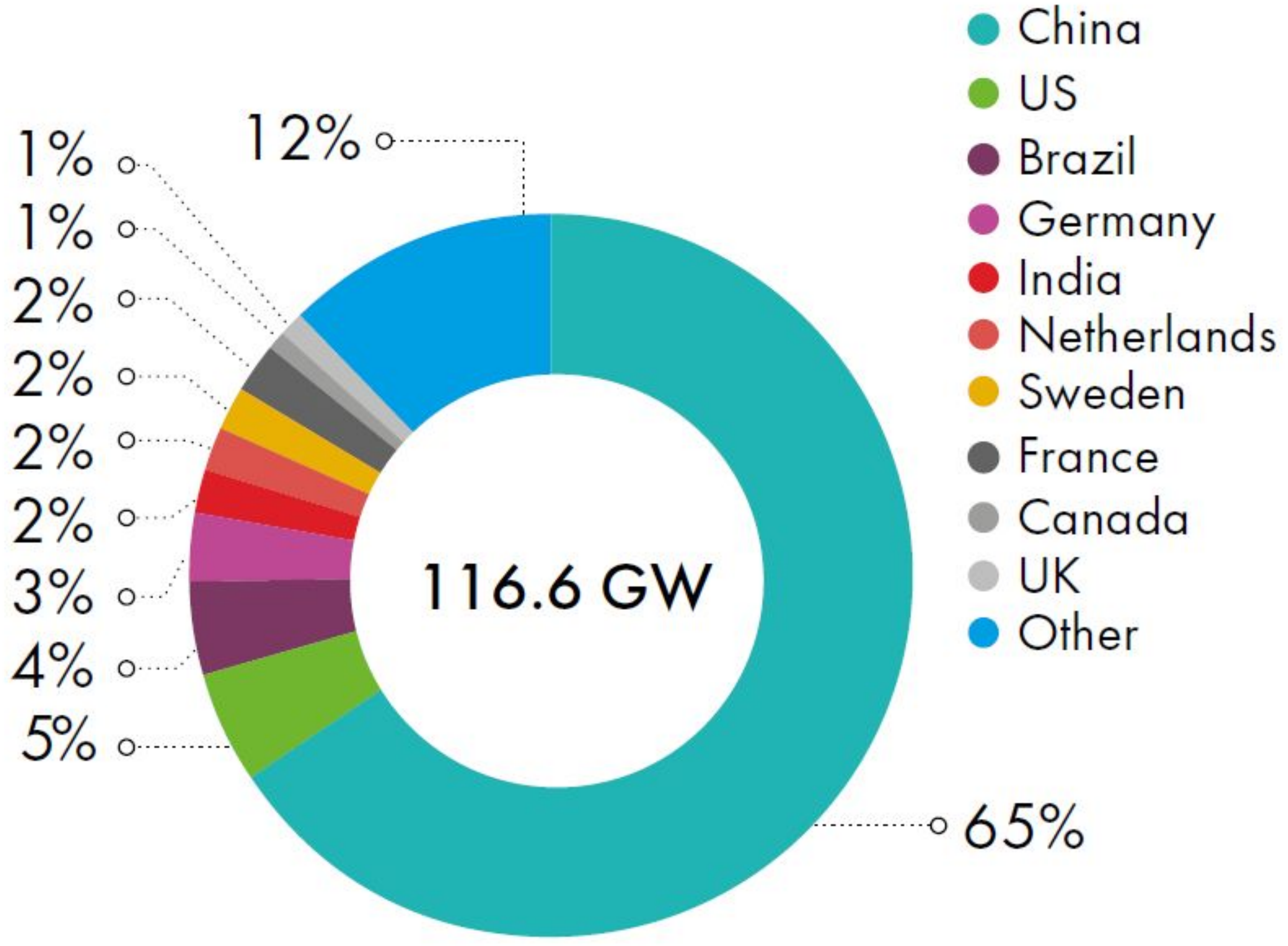
Wind energy trends in the world

- Historic development of total installations (GW):



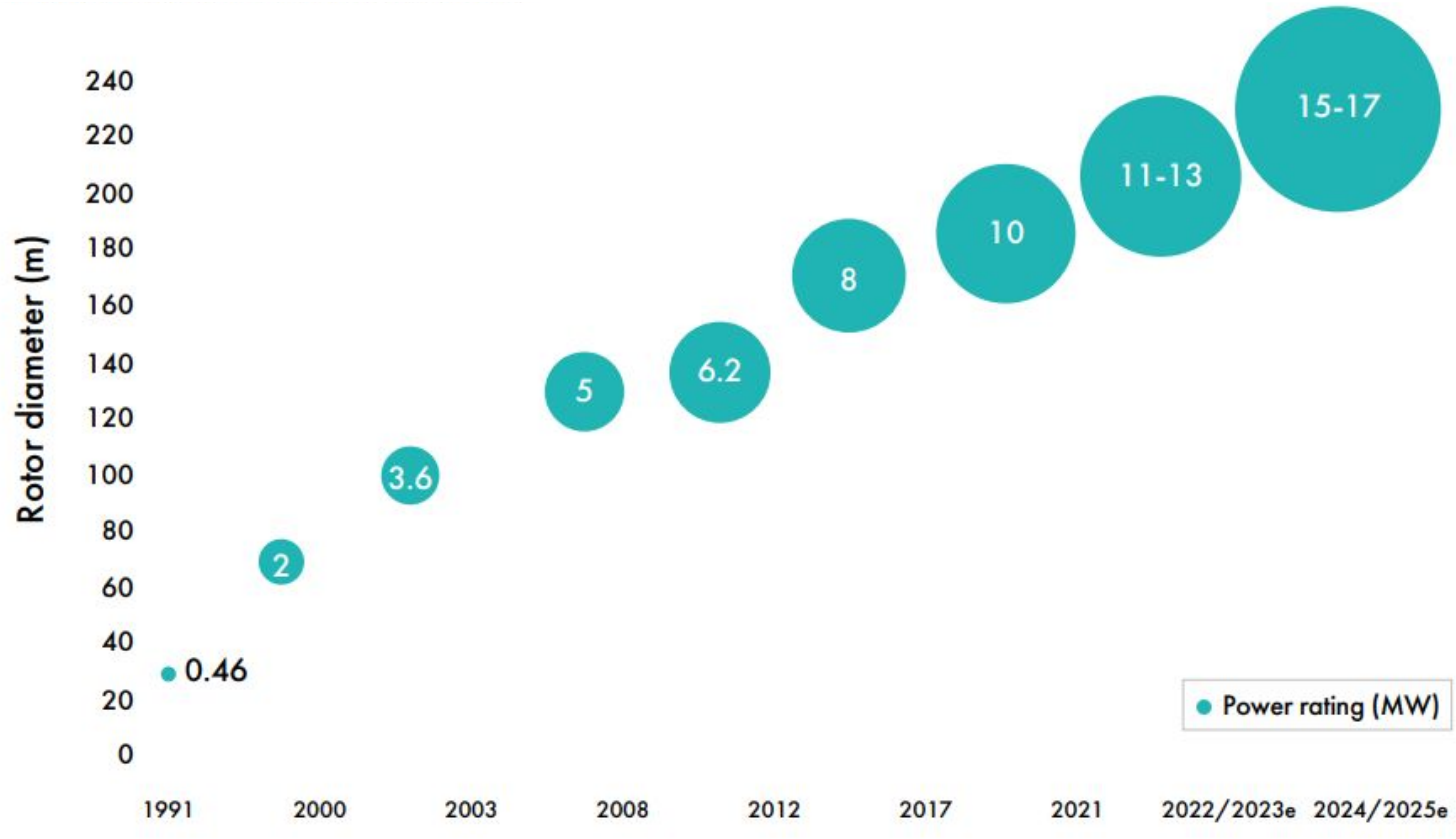
Source: GWEC | GLOBAL WIND REPORT 2024

- New capacity (2023) and markets (%):



Source: GWEC | GLOBAL WIND REPORT 2024

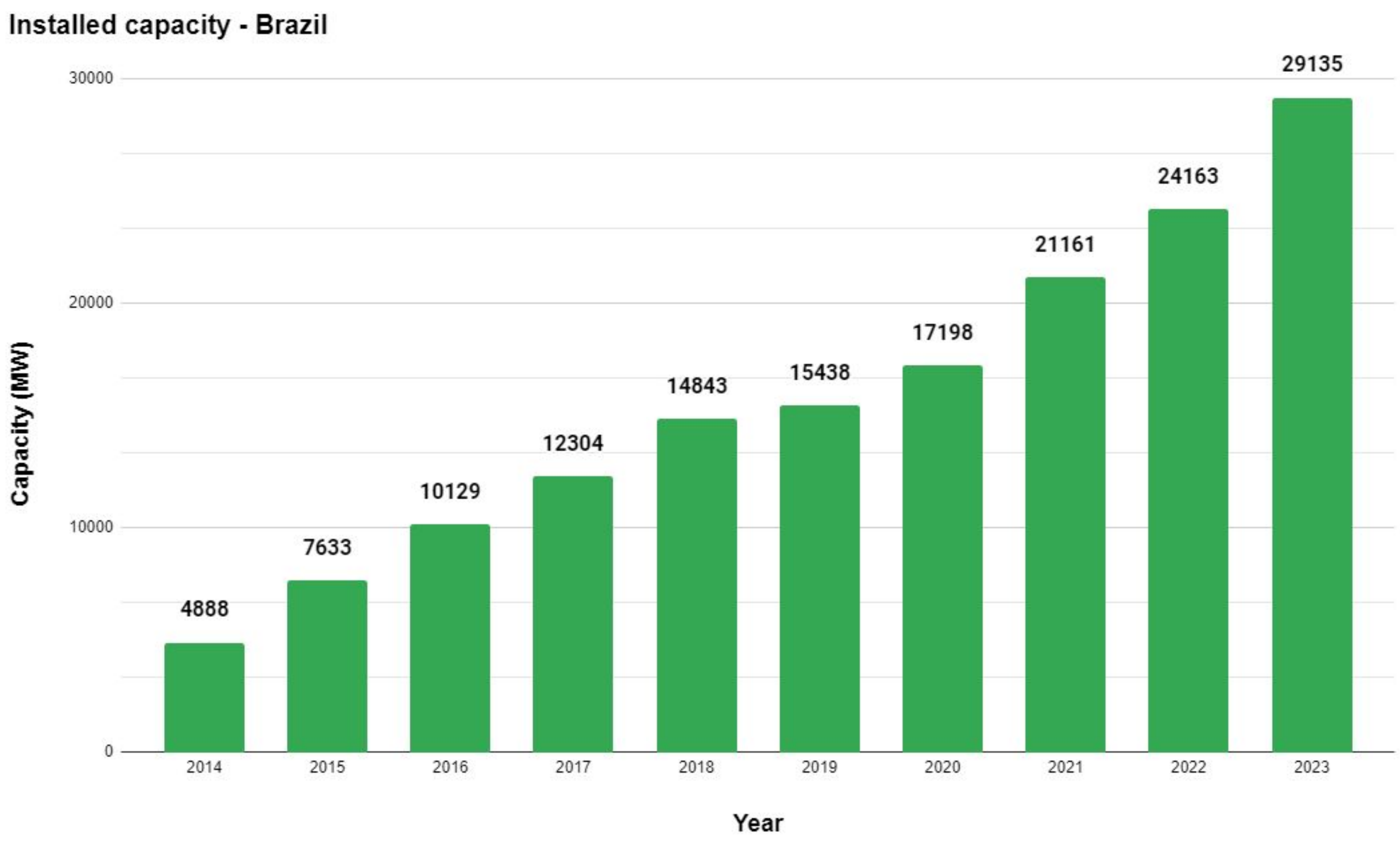
Rotor size and power rating over the years (Offshore parks)



Source: GWEC Market Intelligence, June 2022

Wind energy trends in Brazil

- We have reached the mark of 30 GW in installations (2024).

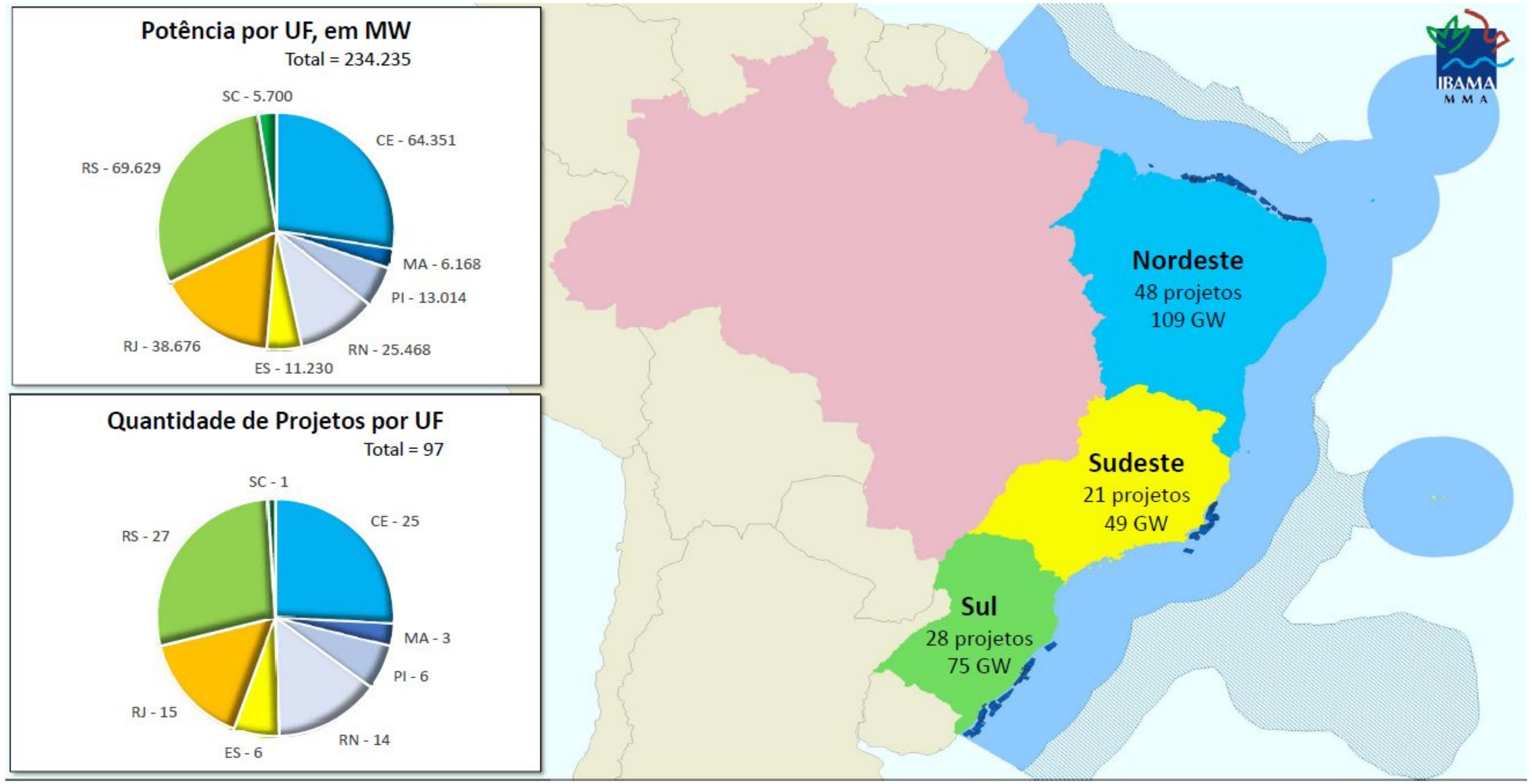


Source: IRENA | Renewable Energy Statistics 2024

Finding the area – Existing Project

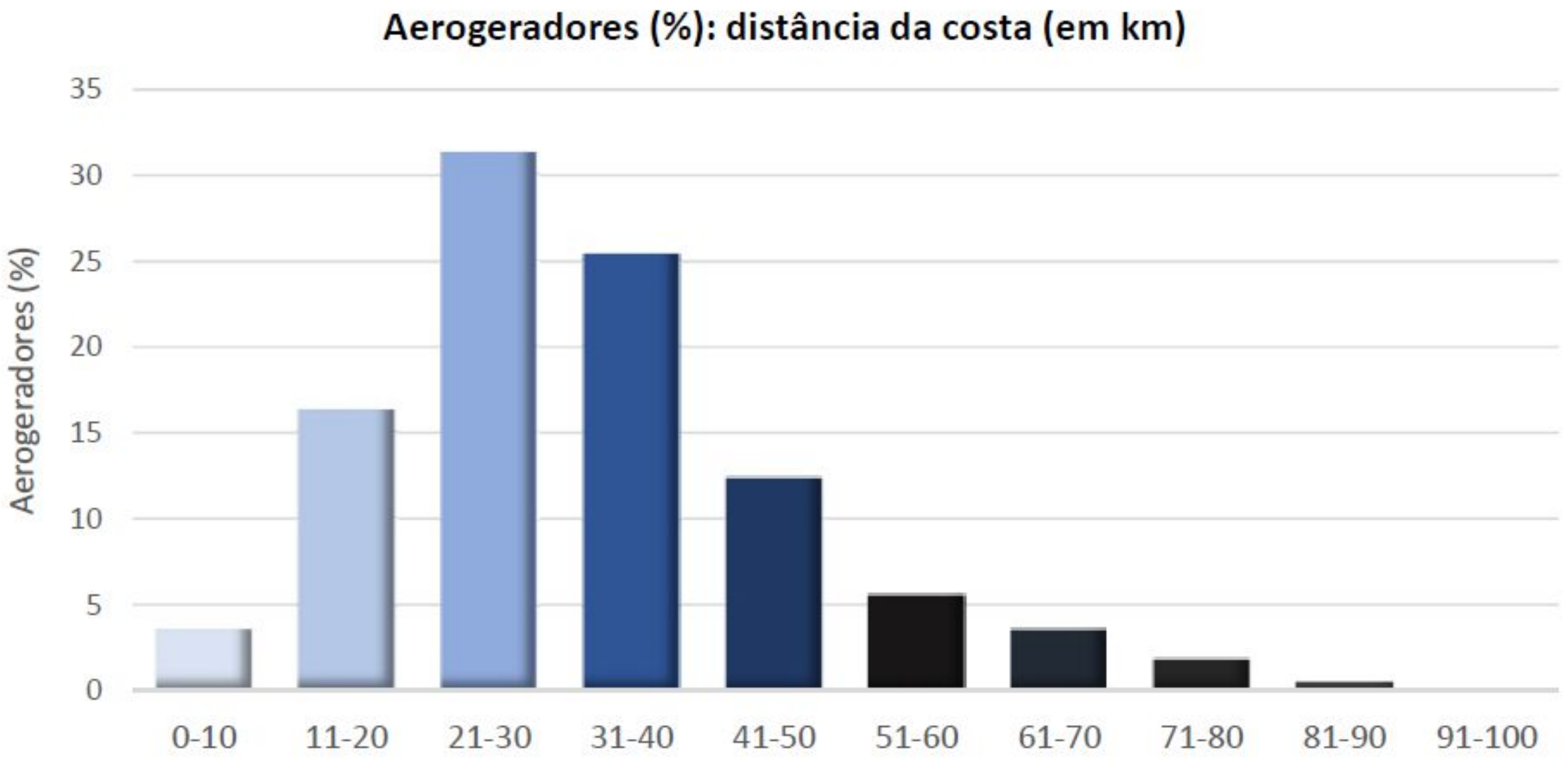
▪There are currently 97 projects waiting for approval in IBAMA, divided into three main regions:

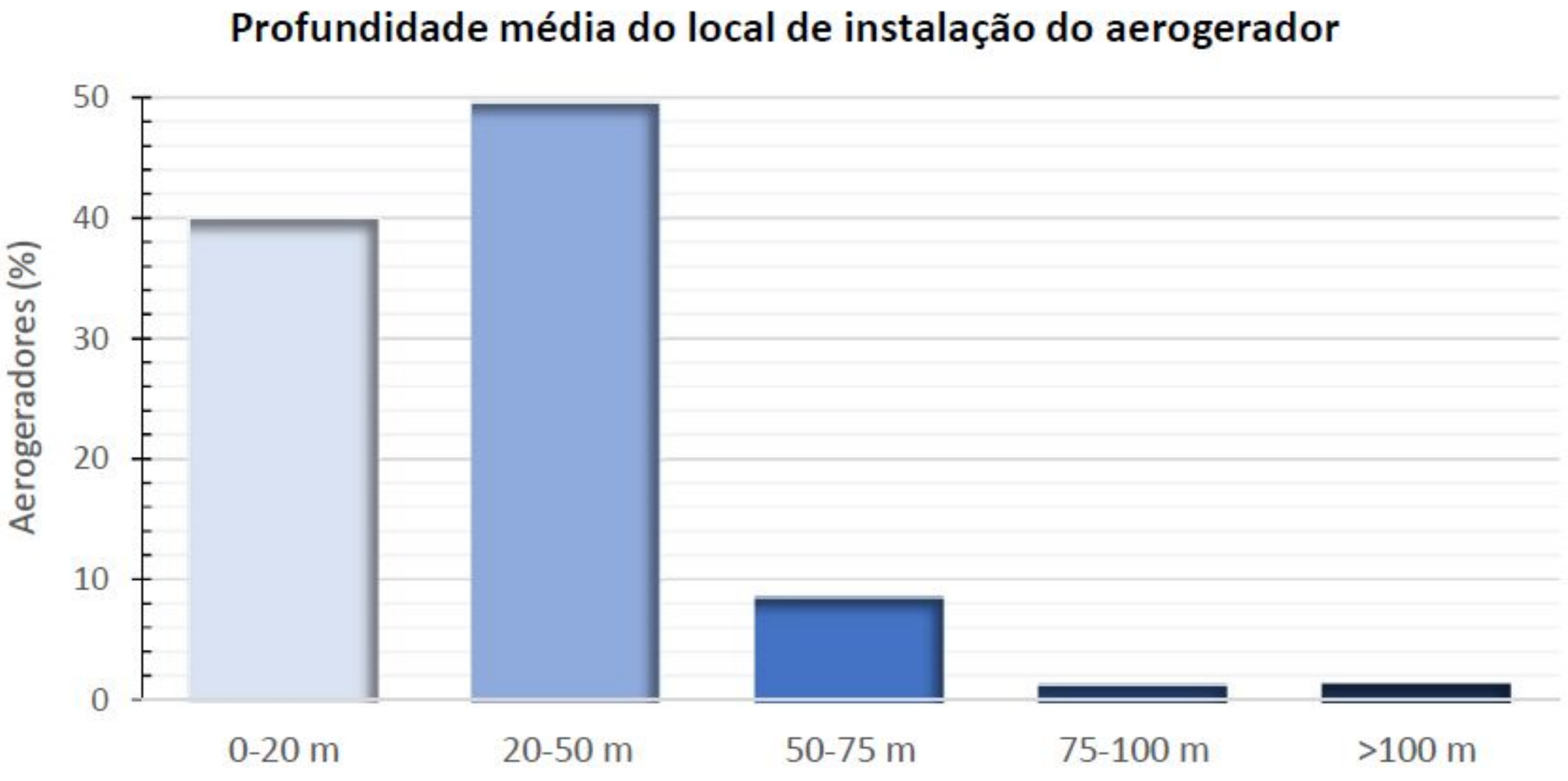
- ❑ Northeast: 48 projects, totalizing 109GW
- ❑ Southeast: 21 projects, totalizing 49GW
- ❑ South: 28 projects, totalizing 75GW



Finding the area – Existing Project characteristics

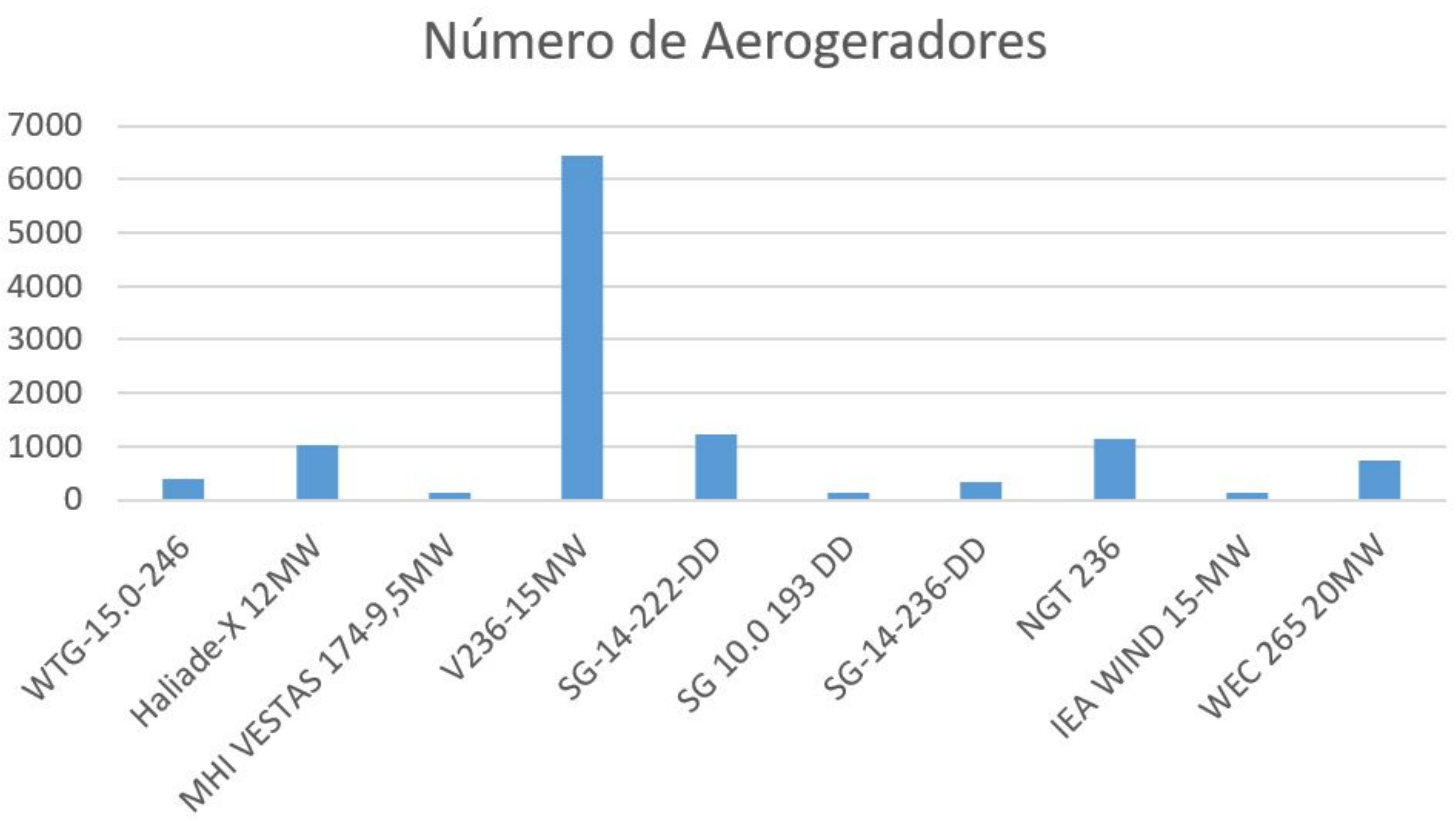
- The majority of turbines are located between 11km and 40km from the coast, at depths of up to 50 meters

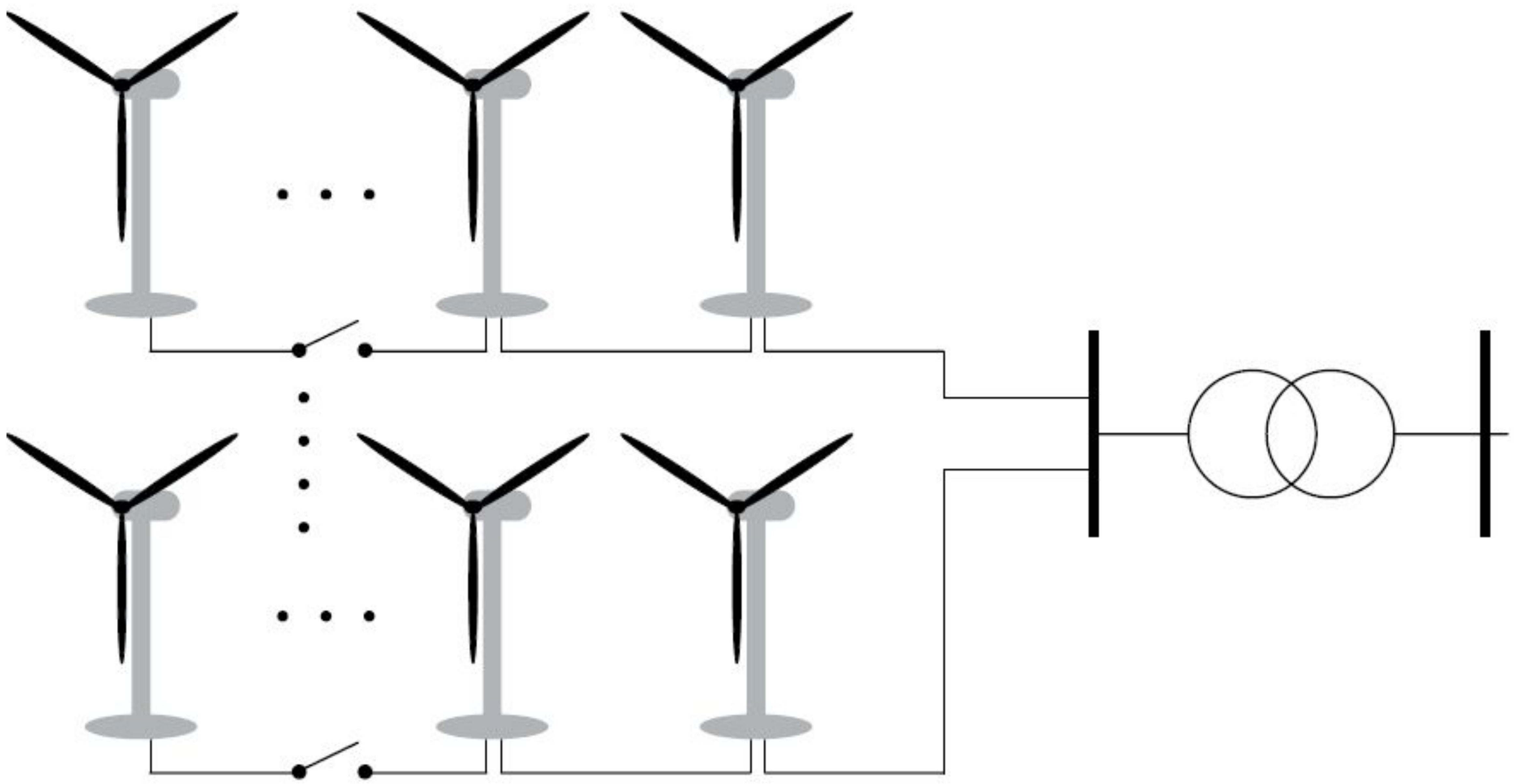




Finding the area – Existing Project characteristics

- The most broadly used model is the Vestas V236-15MW, positioned accordingly to the radial layout





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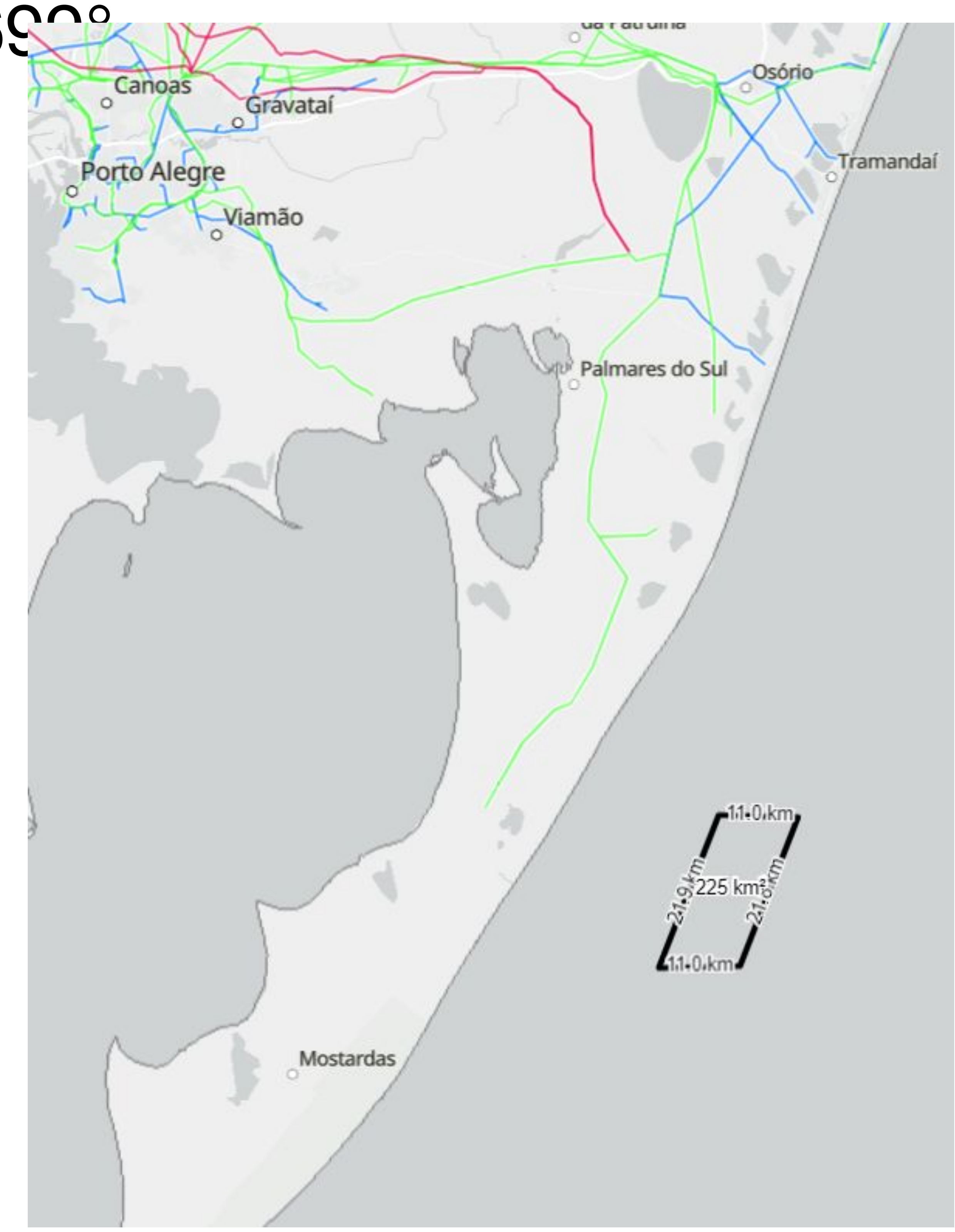
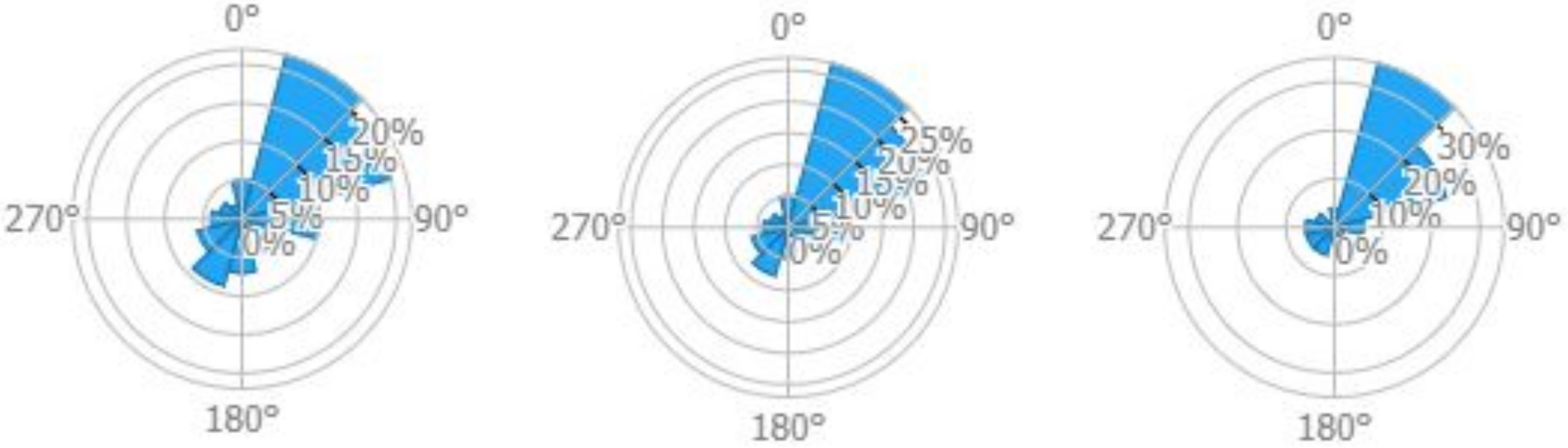
Finding the area – Chosen area

- Characteristics:
  - 20km from the coast
  - Area: 225km2
  - Mean wind speed: 9,64 m/s
  - Center coordinates: -30.884445°, -50.296



- Wind variation between the months:

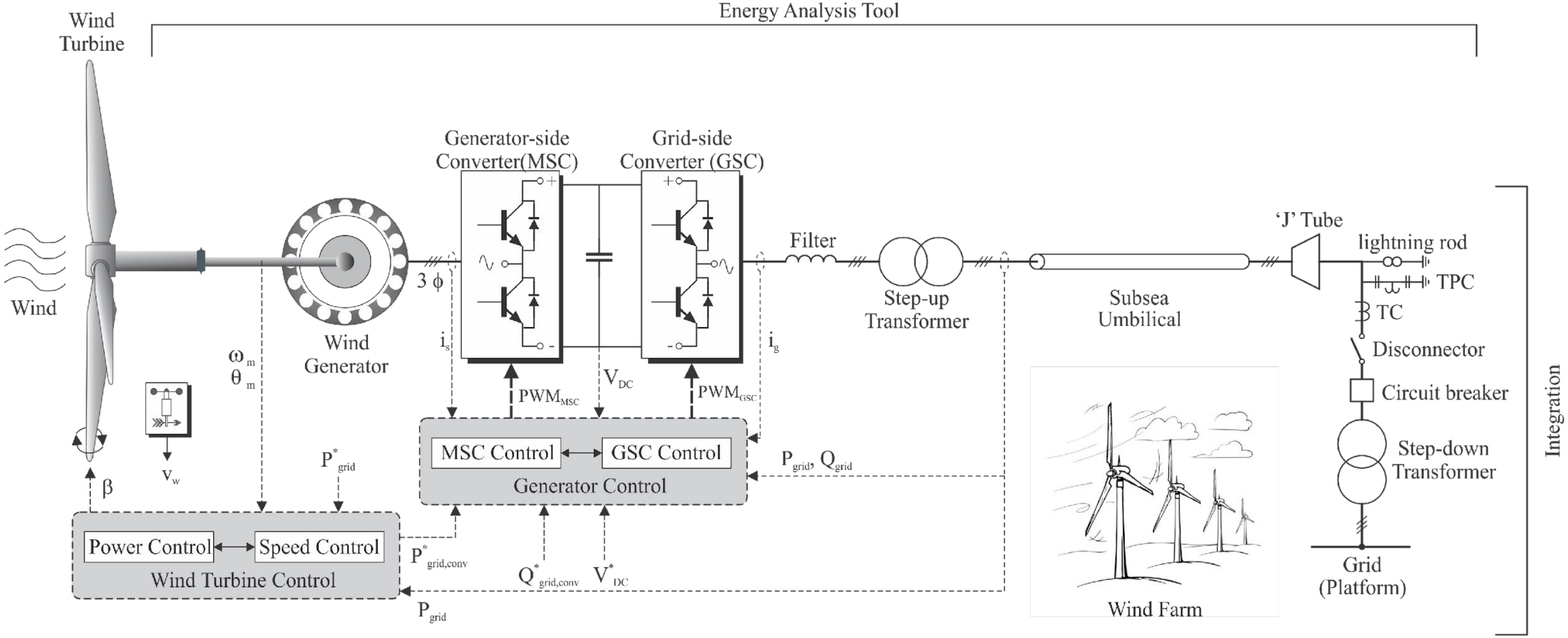
- Wind frequency, speed and power, respectively:



WIND SYSTEM - PROJECTS

Interconnection Evaluation of an Offshore Wind Generation for a 13.8kV Electric System Typical of a UEP Libra

System Model + System Control+Energy Analysis Tool

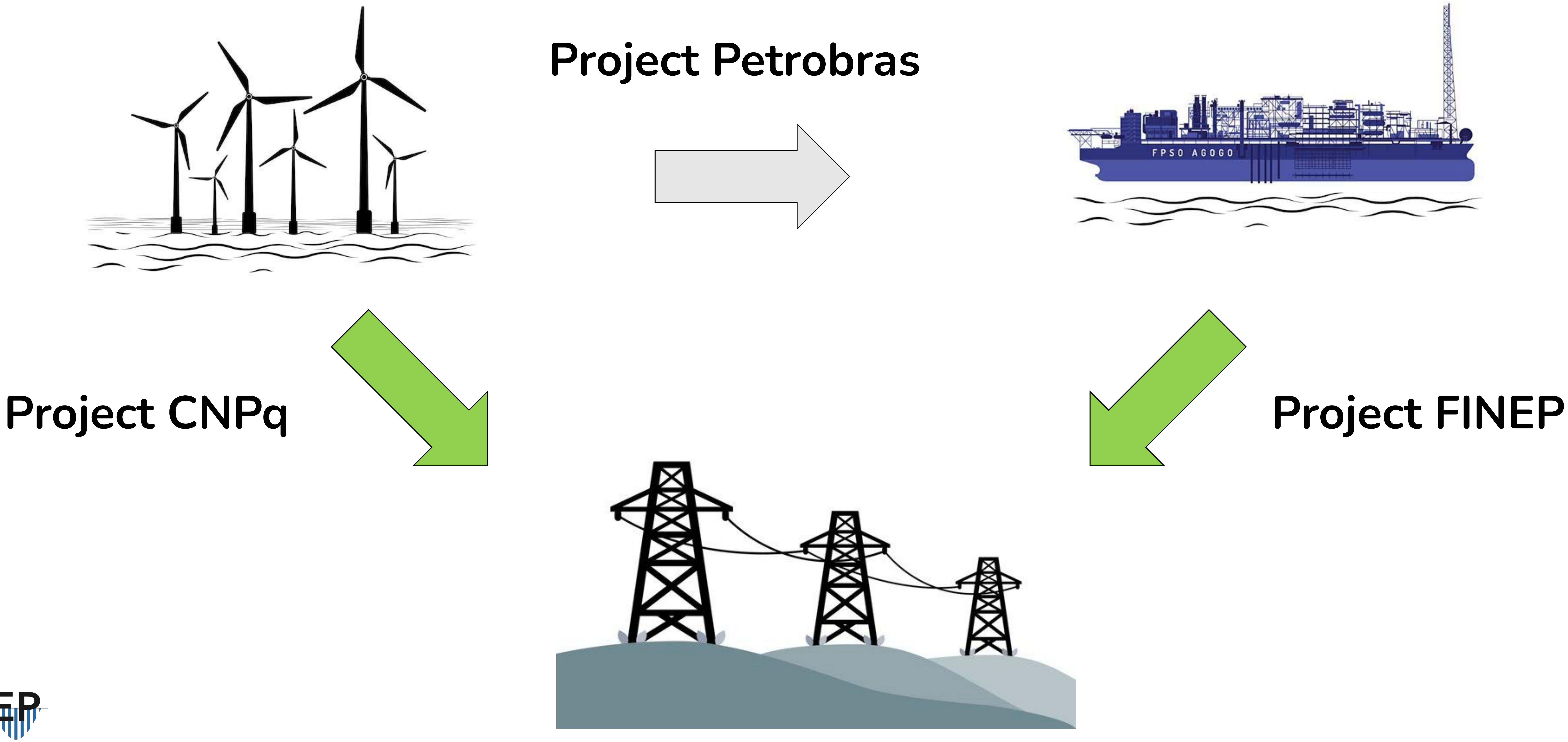


- Two cases (10 MW turbine):
  - An umbilical of 10 km (WT close to the FPSO)
  - An umbilical of 150 km km (WT close to the cost)

COMPLETED

Interconnection Evaluation of an Offshore Wind Generation for a 13.8kV Electric System Typical of a UEP Libra

- Resulted in new projects:



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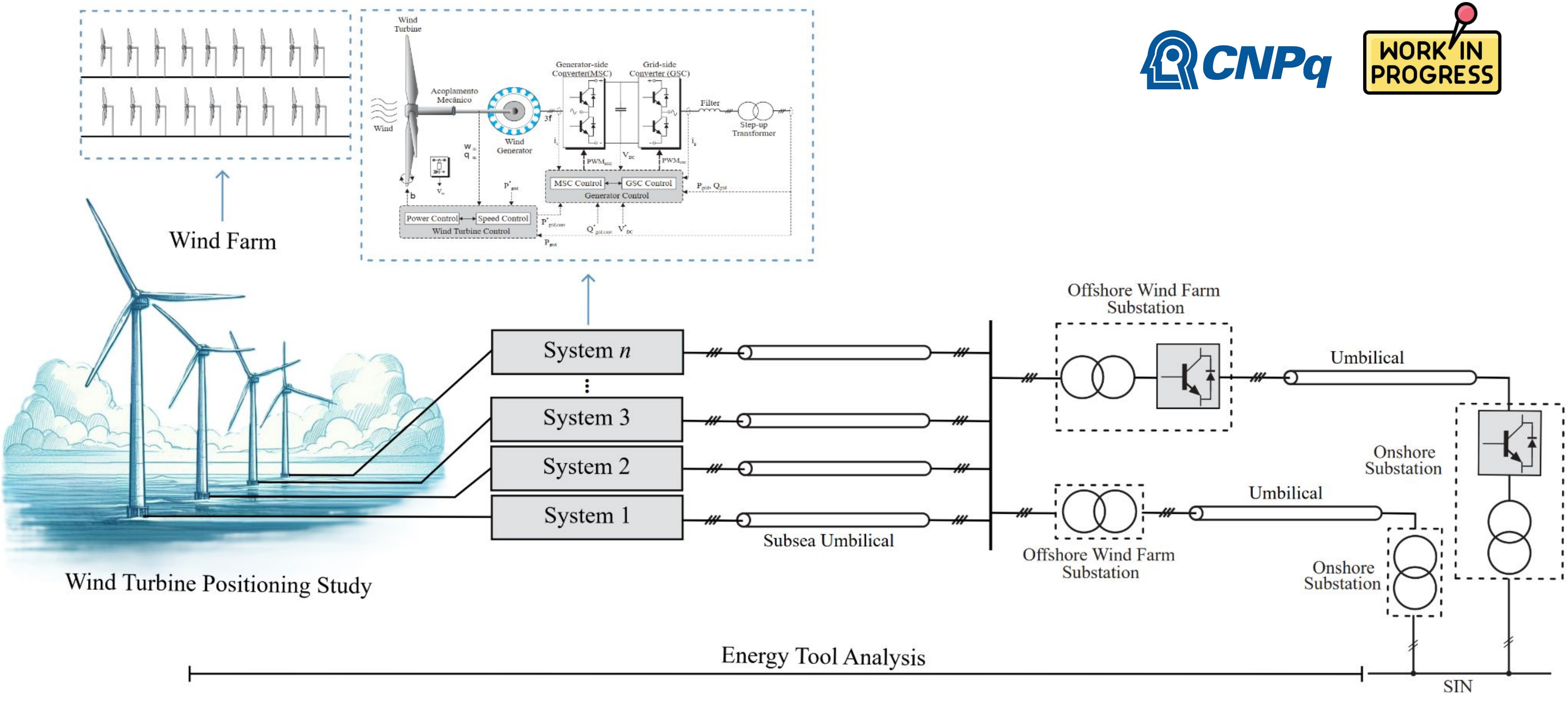
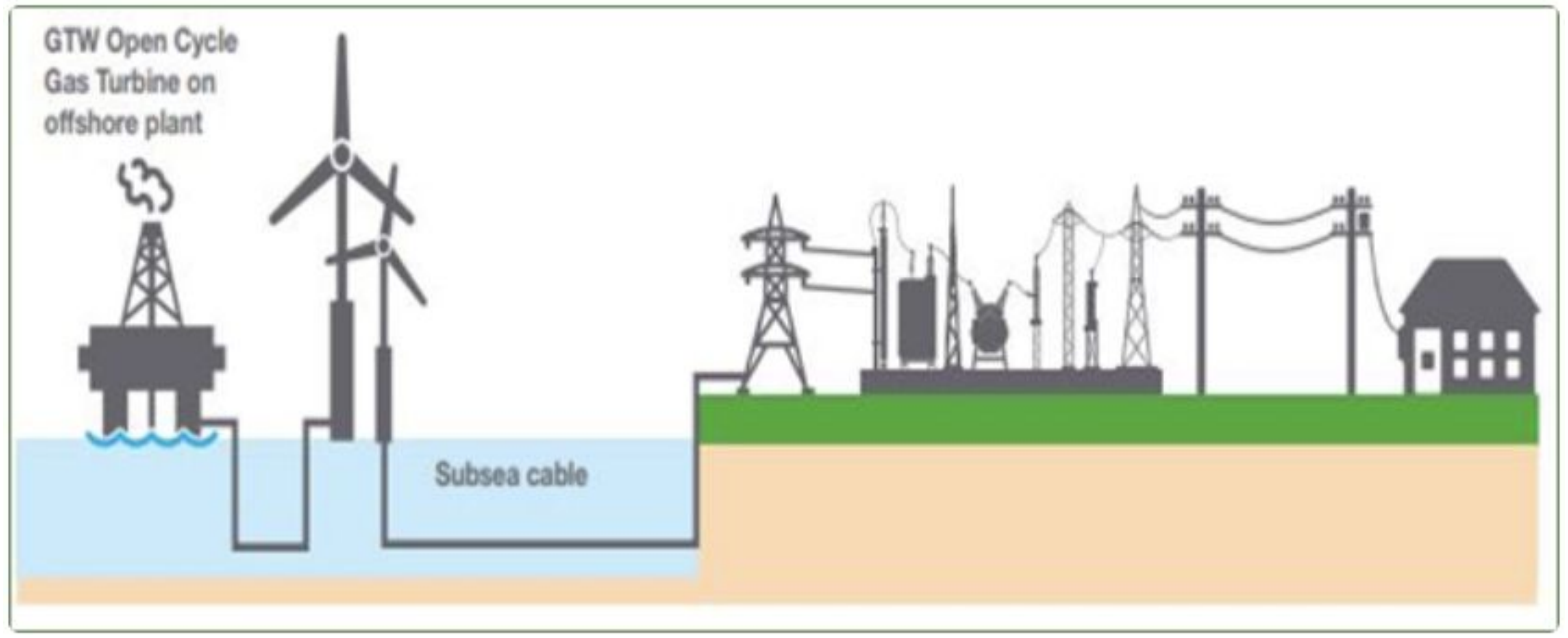
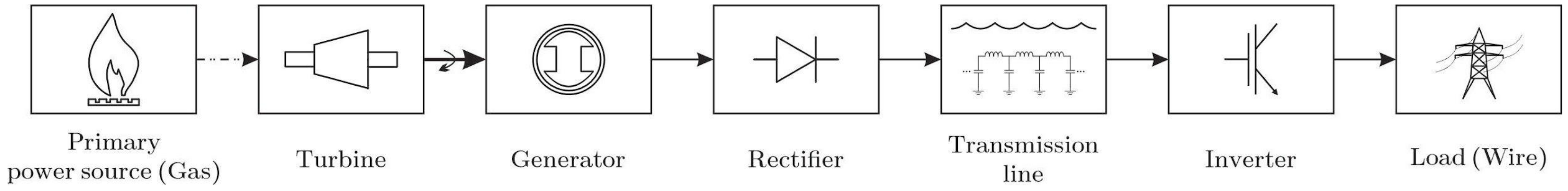
Contributions to Offshore Wind Systems in the Development of Electrical Models for Generation, Transmission and Connection with the SIN for Project Studies, Energy Capacity, Operation and Stability



Project with FINEP – Gas to Wire (G2W)

- Development of a compact gas-to-wire conversion system using natural gas applied to oil platforms:





Proposed system. Source: report to FINEP

- Some challenges:
  - Combined cycle gas turbine model;
  - Dynamical modeling of the transmission line and power converters;
  - Design the control system;
  - Proposing a compact natural gas to electrical energy conversion system;
  - Experimental validation.

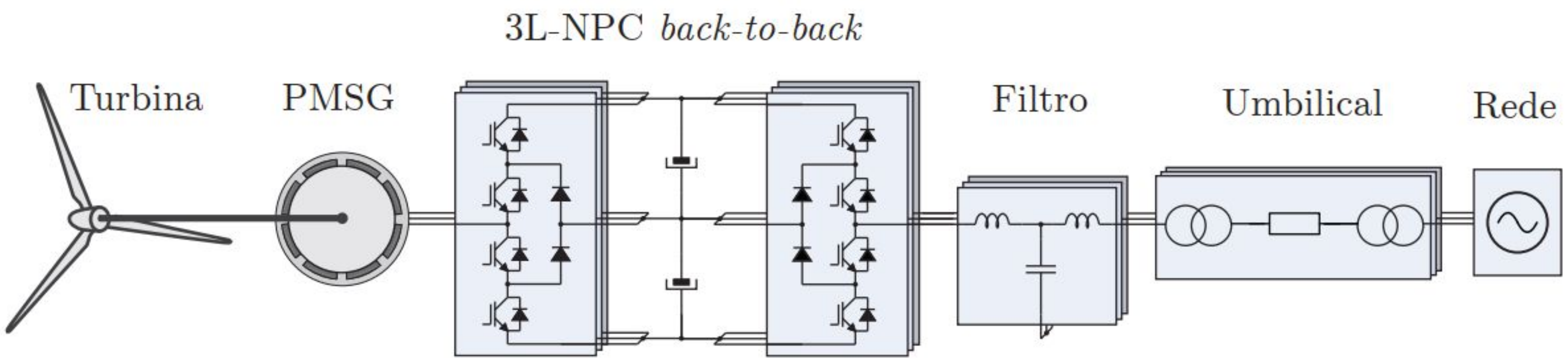
INEP

Finep INOVAÇÃO E PESQUISA

WORK IN PROGRESS

Methodologies for Designing Frequency Controllers in Offshore Wind Energy Conversion Systems Connected to Isolated Grids

UFSC



Turbina	PMSG	Conversor	Barramento CC	Conversor	Filtro	Umbilical
16 MW	15,2 MW	18 MVA	7,2 kV	18 MVA	LCL + RC	30 kV / 400 mm^2
5 – 7,6 rpm	4,77 kV	4,77 kV		3,5 kV		10 km / 50 km
10,59 m/s	0,84 PF	900 Hz (f_s)		900 Hz (f_s)		
		12,6 Hz (f_o)		60 Hz (f_o)		

- Doctorate thesis by: Matheus Schramm Dall'Asta
- Main objective:
  - ❑ Design frequency controllers in a wind energy conversion system to ensure static stability and frequency transient response quality equal to or better than that of a conventional system.

CNPq

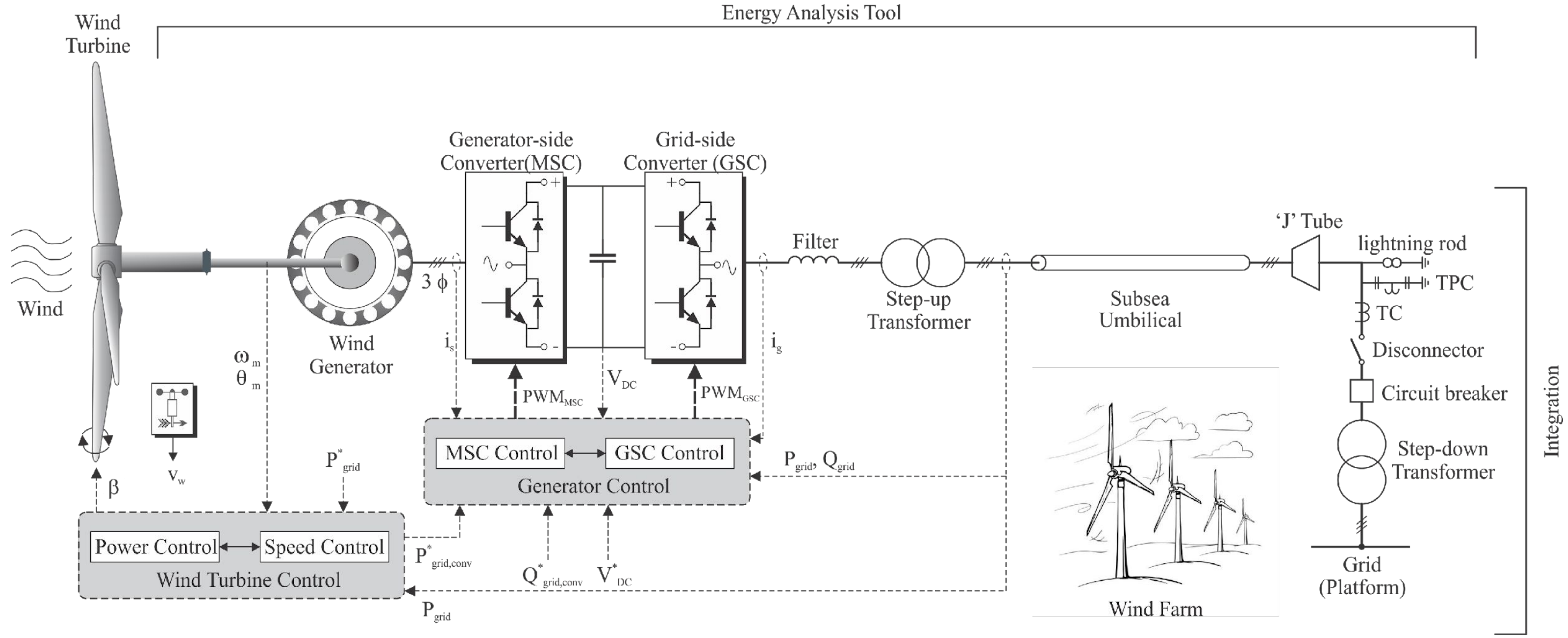
COMPLETED

INTERCONNECTION EVALUATION OF AN OFFSHORE WIND GENERATION FOR A 13.8 KV ELECTRIC SYSTEM TYPICAL OF A UEP LIBRA

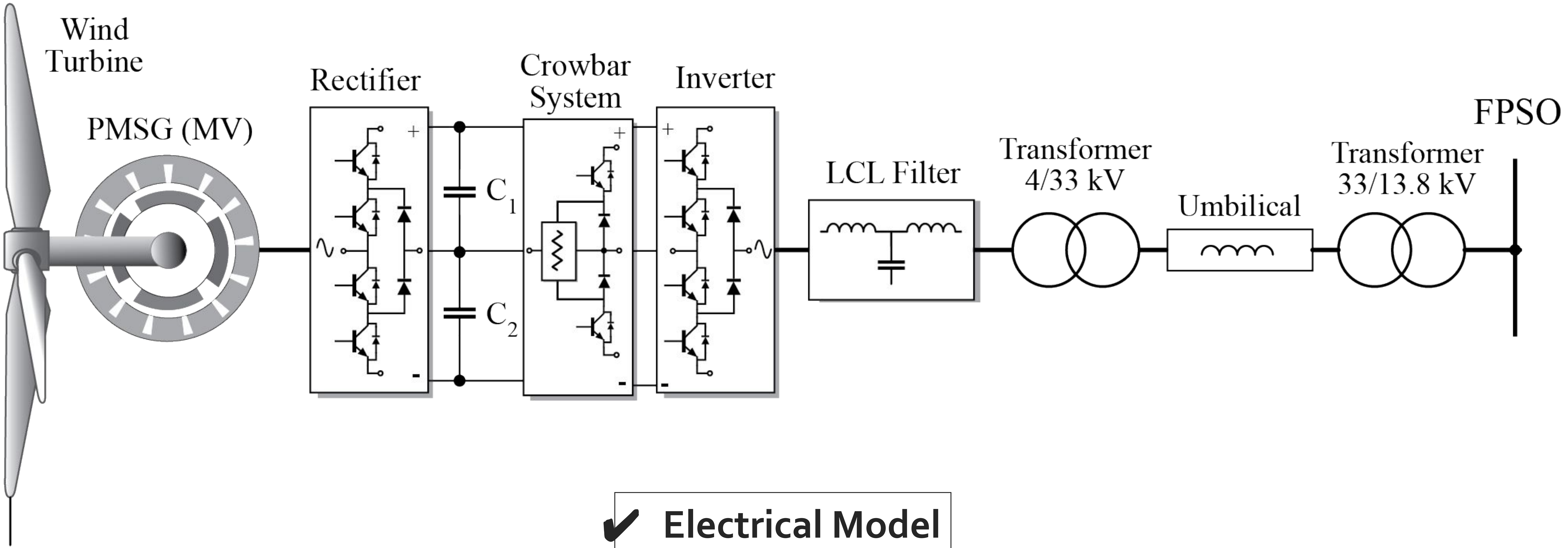
COMPLETED

Project Presenting

- **Main Objective:**
  - Technical feasibility of integrate offshore wind energy conversion systems into isolated electrical grids on oil and gas production platforms.
- **Specific Objetives:**
  - Electrical modeling and termic and mechanical efforts;
  - Analysis in steady-state, transient and faul operation modes of the plataform grid;
  - Sensitivity analysis of the integration of more than one wind generation unit to a platform.



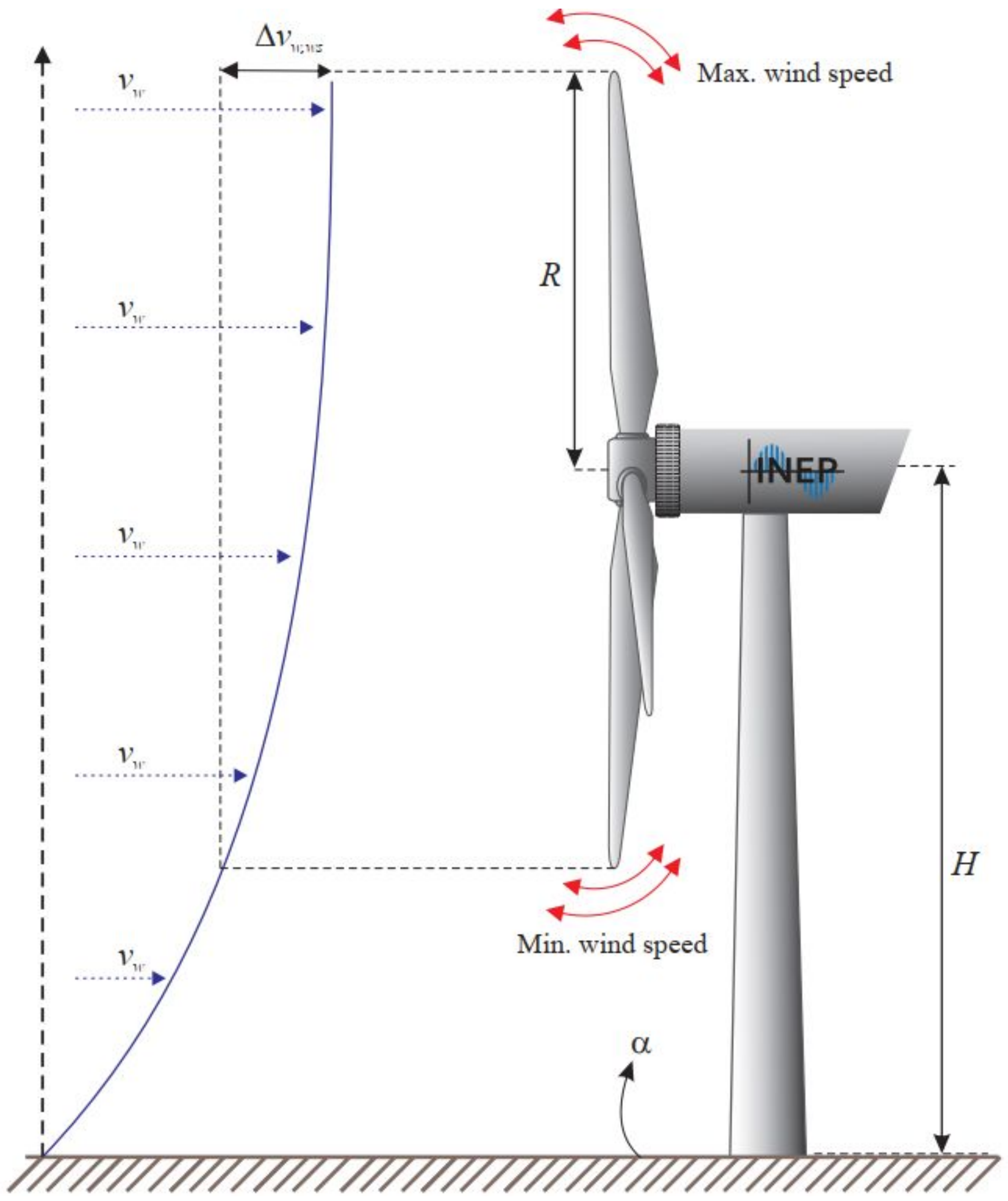
Wind System Modeling



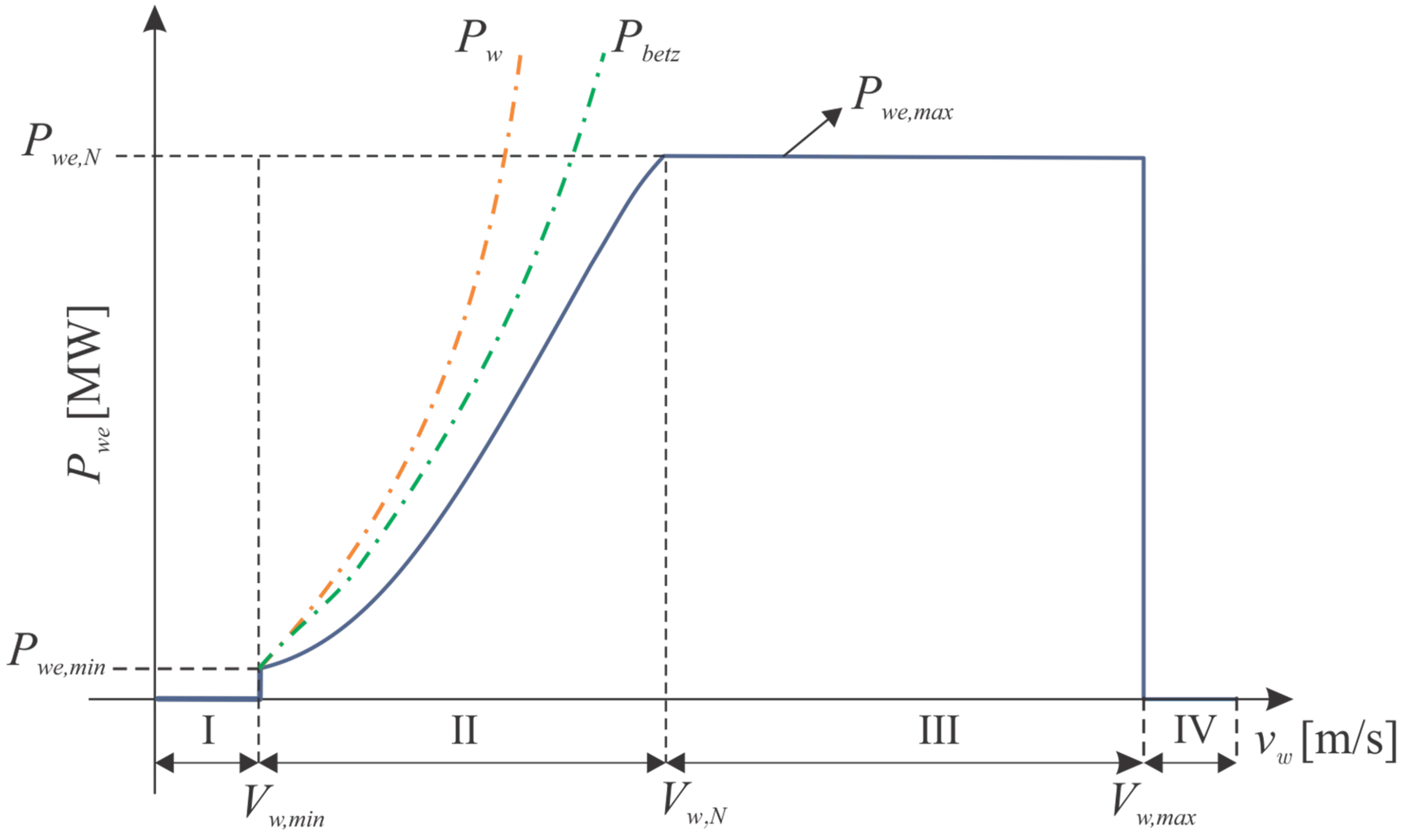
- ✔ Electrical Model
- ✔ Thermal Model

System Model

- Wind Turbine:
  - Aerodynamics;
  - Non-idealities: Wind Shear and Tower Shadow.

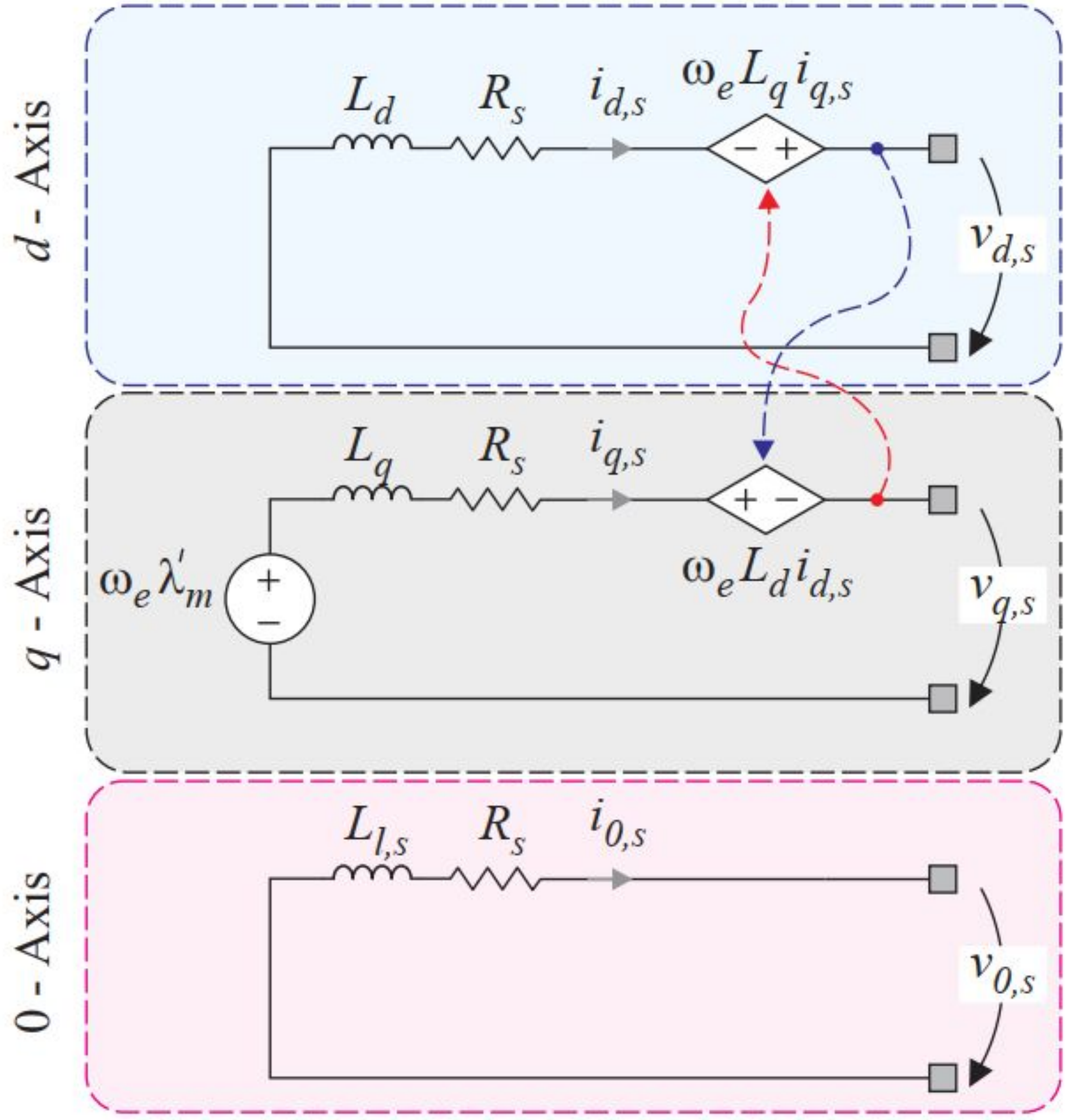


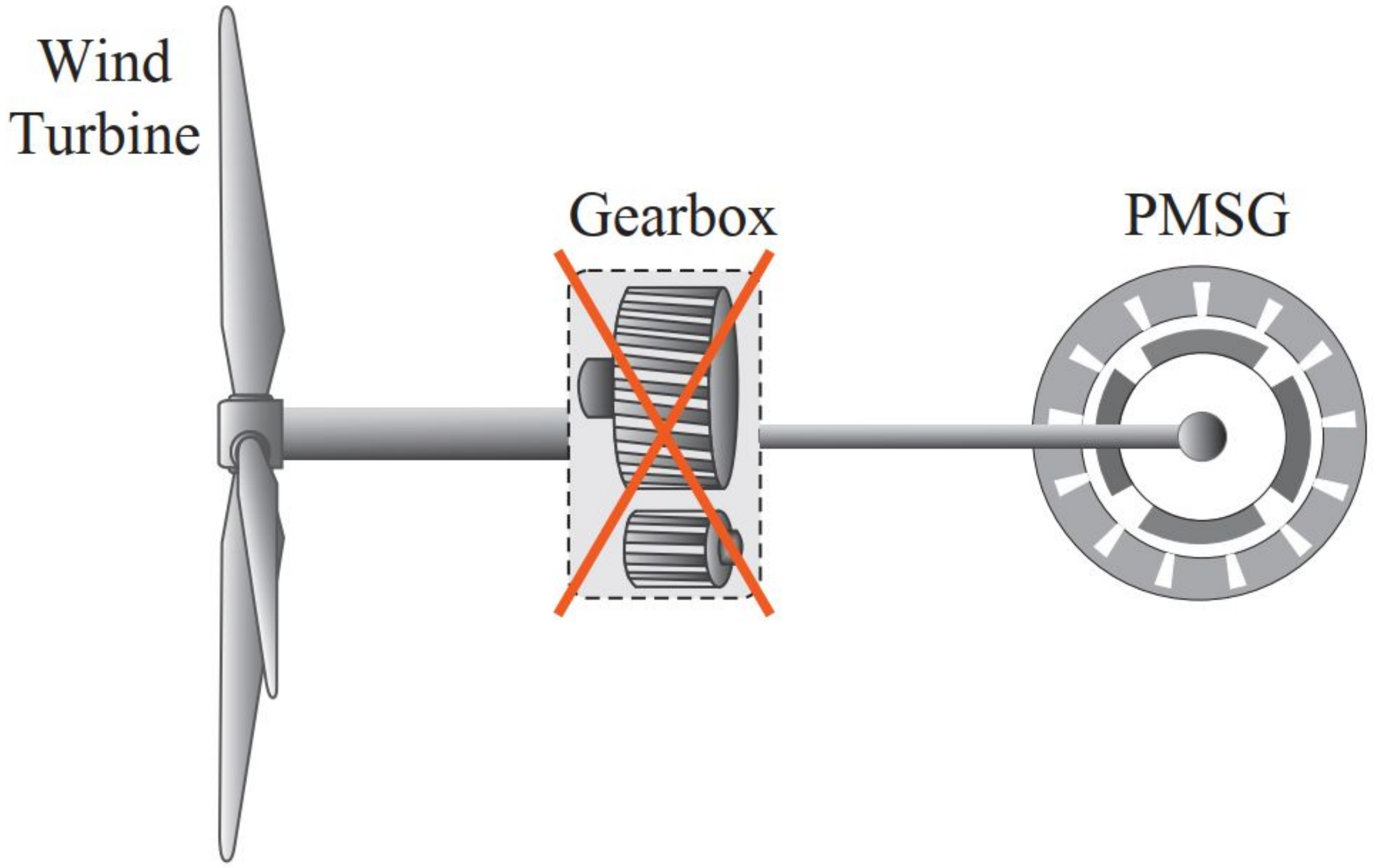
Parameter	Symbol	Value
Rated Power	$P_{we,N}$	11 MW
Rated Torque	$T_{we,N}$	10,5 MN·m
Rated Speed	$\omega_{r,N}$	10 rpm
Cut-in Wind Speed	$V_{w,min}$	4 m/s
Rated Wind Speed	$V_{w,N}$	11 m/s
Cut-out Wind Speed	$V_{w,max}$	25 m/s
Maximum Power Coefficient	$C_{p,max}$	0,453
Maximum Tip Speed Ratio	λ_{max}	9,165



System Model

- Permanent Magnet Synchronous Generator:



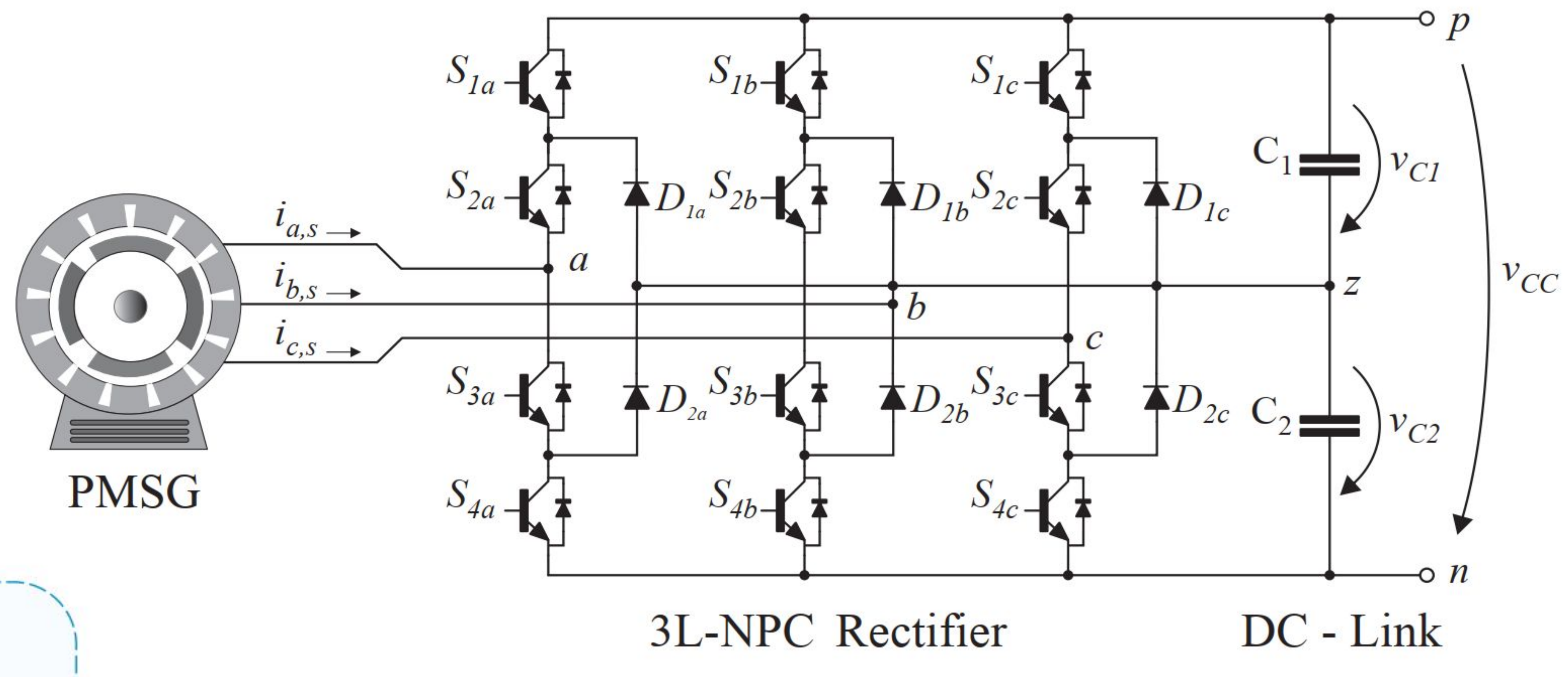


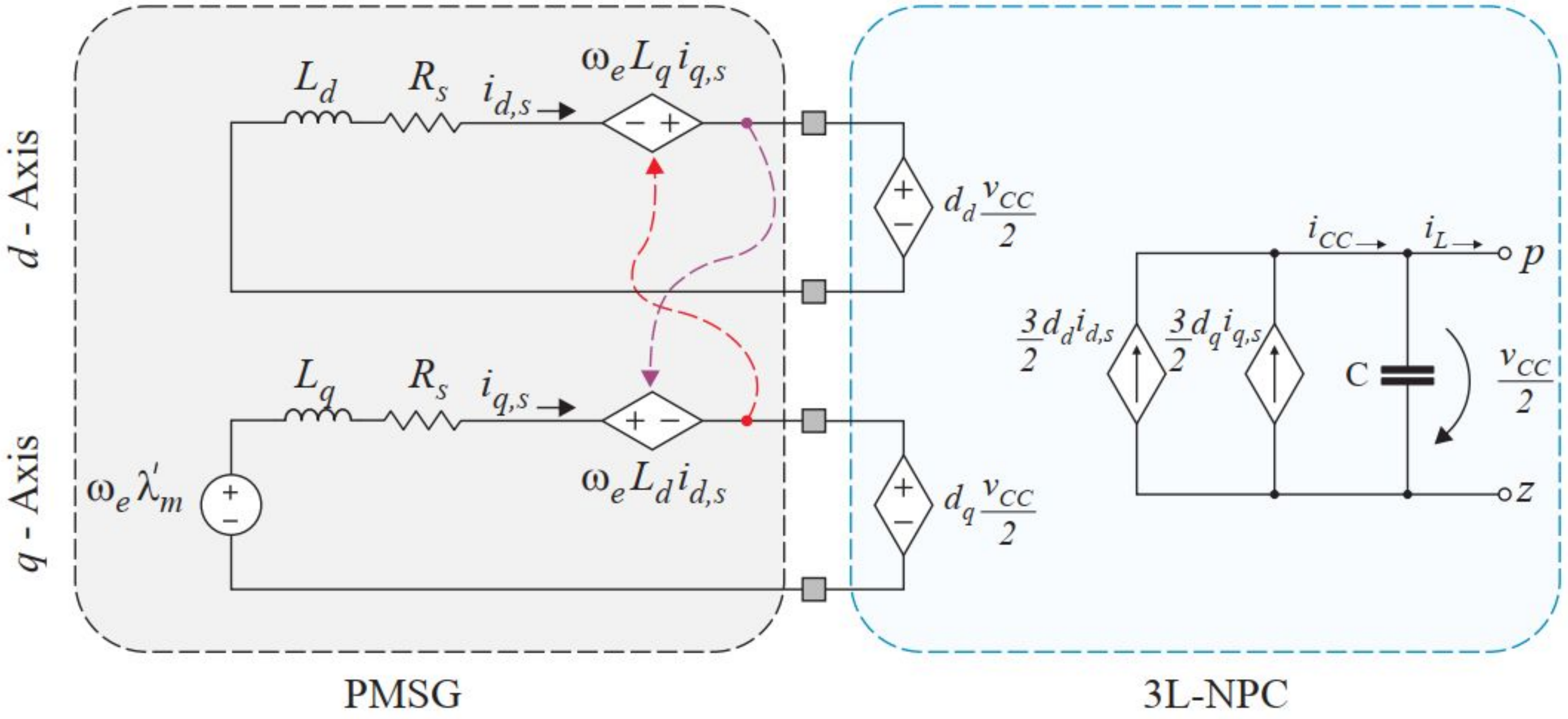
Parameter	Symbol	Value
Apparent Power	$S_{g,N}$	10,8 MVA
Active Power	$P_{g,N}$	10 MW
Speed	$\omega_{g,N}$	10 rpm
Voltage	V_{llg}	4000 V
Current	I_s	1443 A
Frequency	f_e	26,66 Hz
Pole Number	P	320

✔ **Electrical Model**
✔ **Thermal Model**

System Model

- Rectifier:
  - Two parallel-connected Three-Level Neutral Point Clamped (3L-NPC) converters;
  - Optimum Pulse Pattern Modulation – 150 Hz switching frequency;
  - 6.5 kV DC-bus;
  - Specification with commercial componentes.



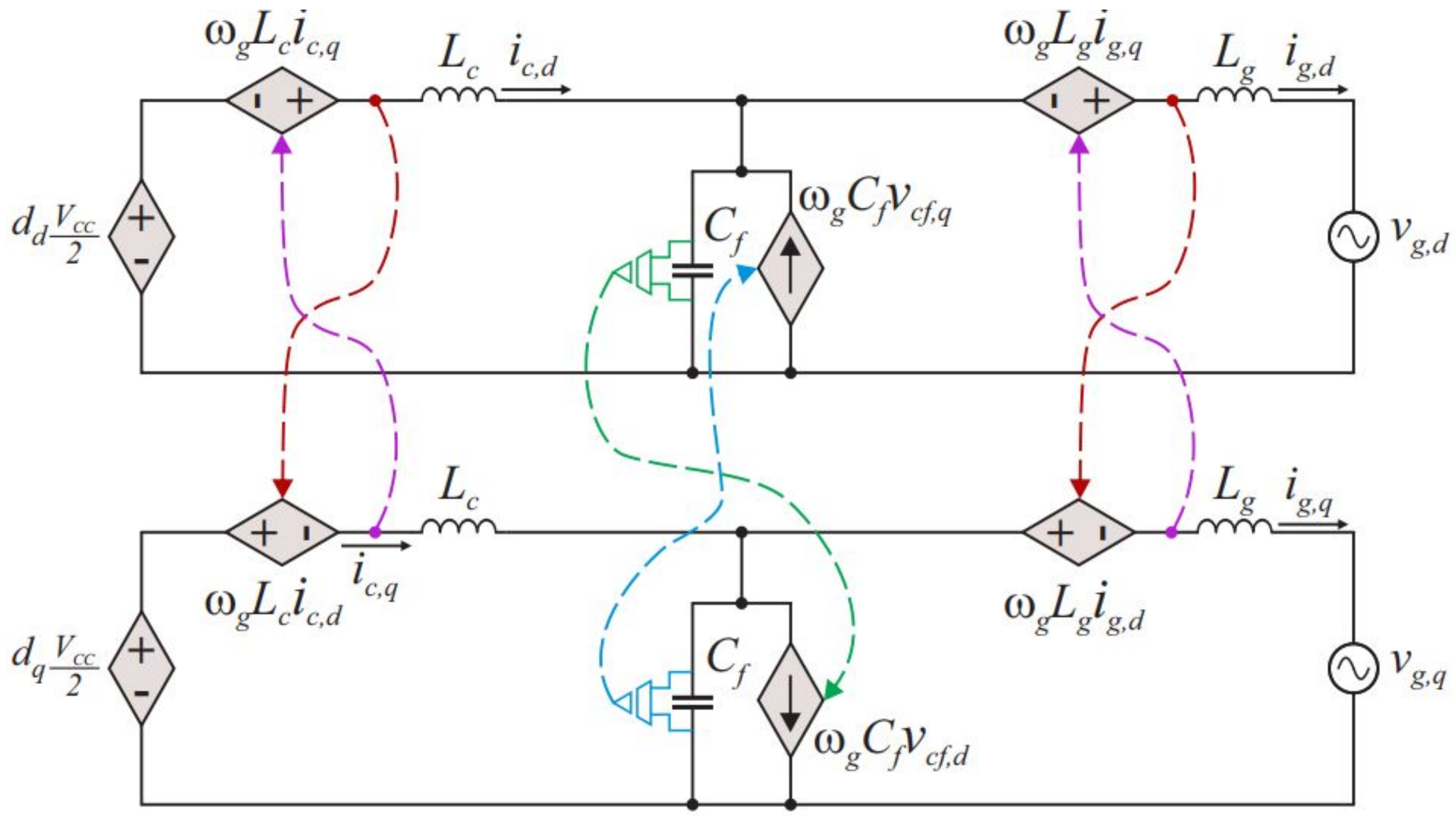


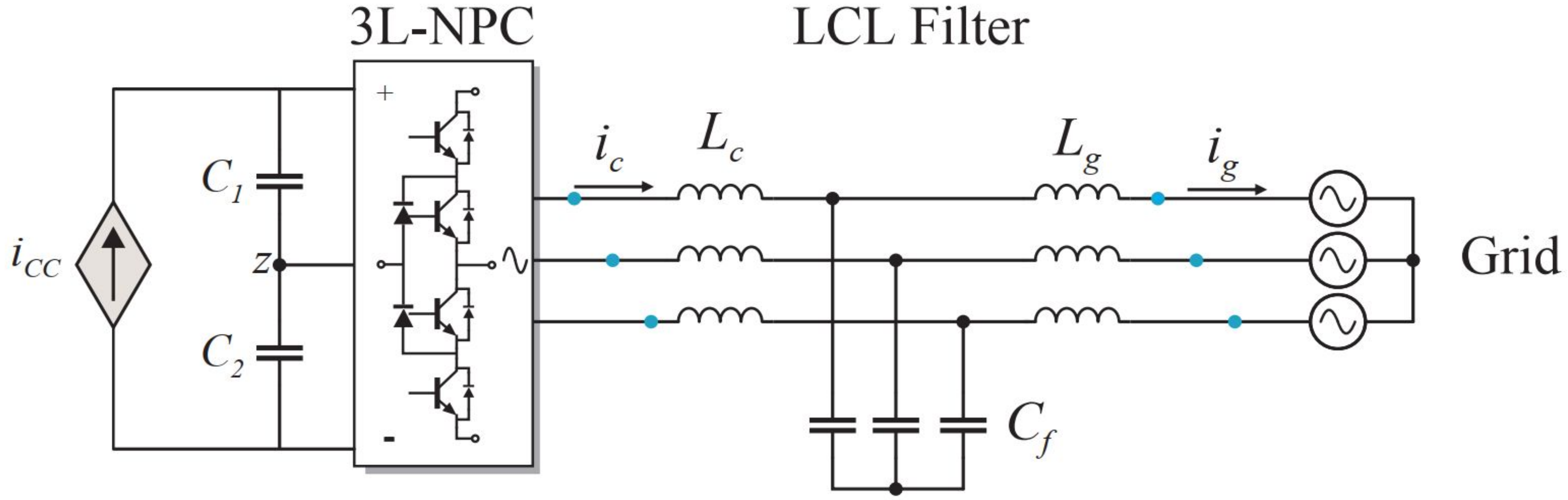
- ✔ **Electrical Model**
- ✔ **Thermal Model**

System Model

- Inverter + LCL Filter:
  - ❑ Two parallel- connected Three-Level Neutral Point Clamped (3L-NPC) converters;
  - ❑ Filter active damping;
  - ❑ 4 kV output voltage;
  - ❑ 1260 Hz swiching frequency;
  - ❑ 15 MVA rated power.

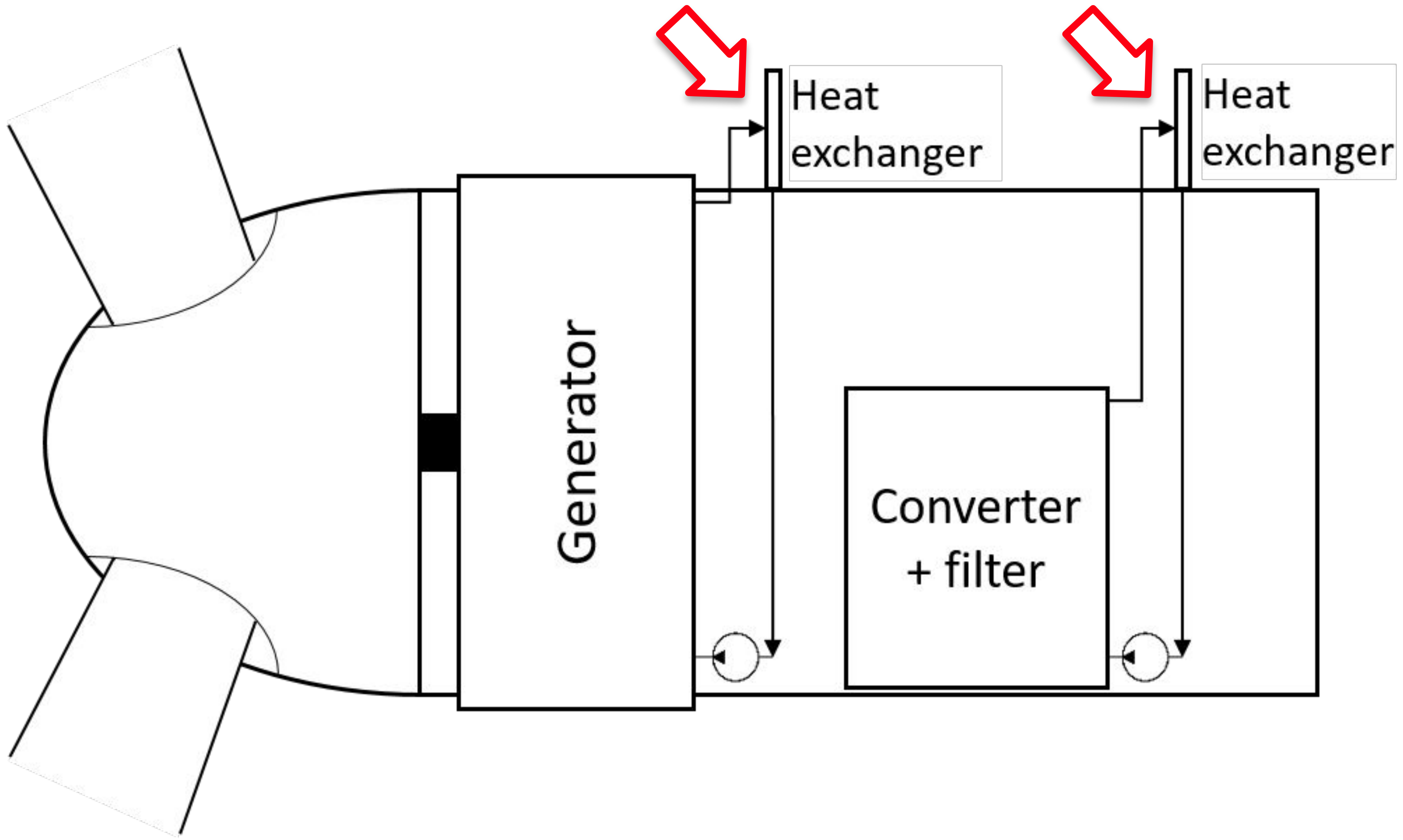
✔ **<u>Electrical Model</u>**
✔ **Thermal Model**

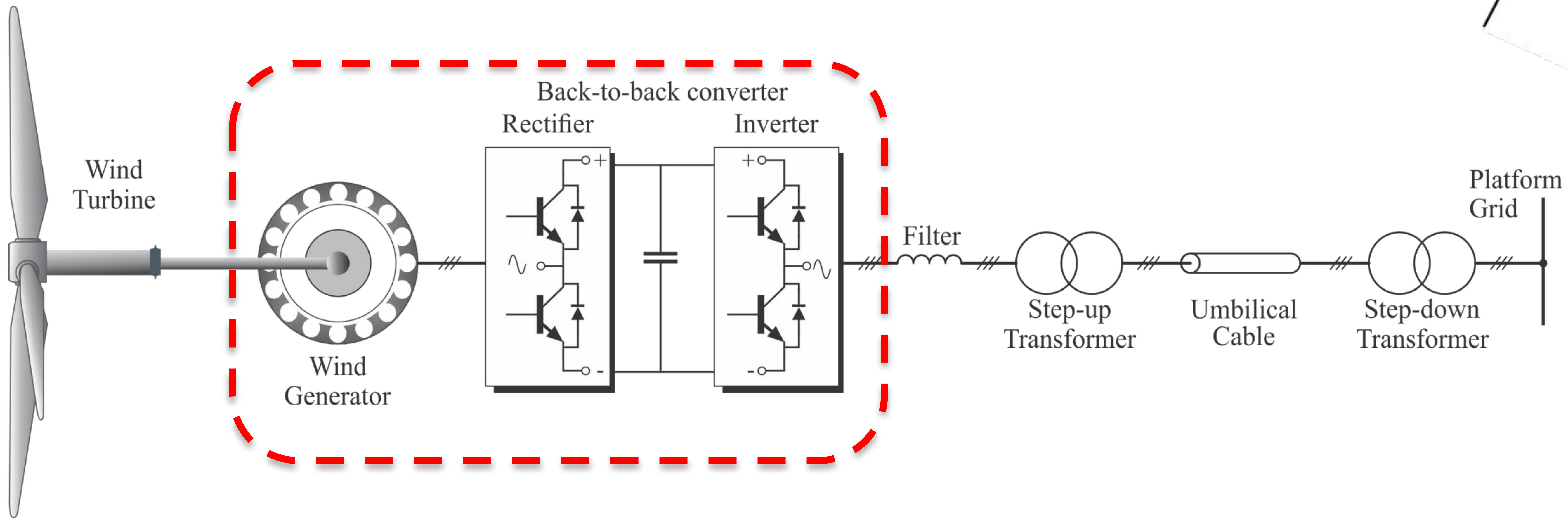




System Model

- Thermal Modeling - Generator and Converter:
  - Thermal losses models: generator and converter;
  - Temperature estimation models: generator and converter;
  - Heat exchangers analysis;
  - Estimation of consumption in auxiliary systems.



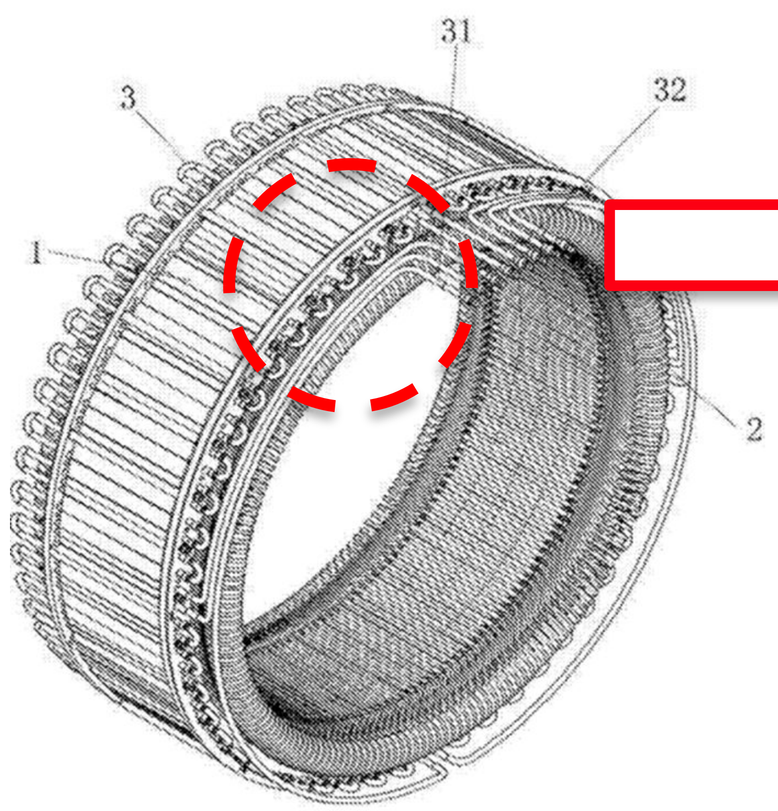


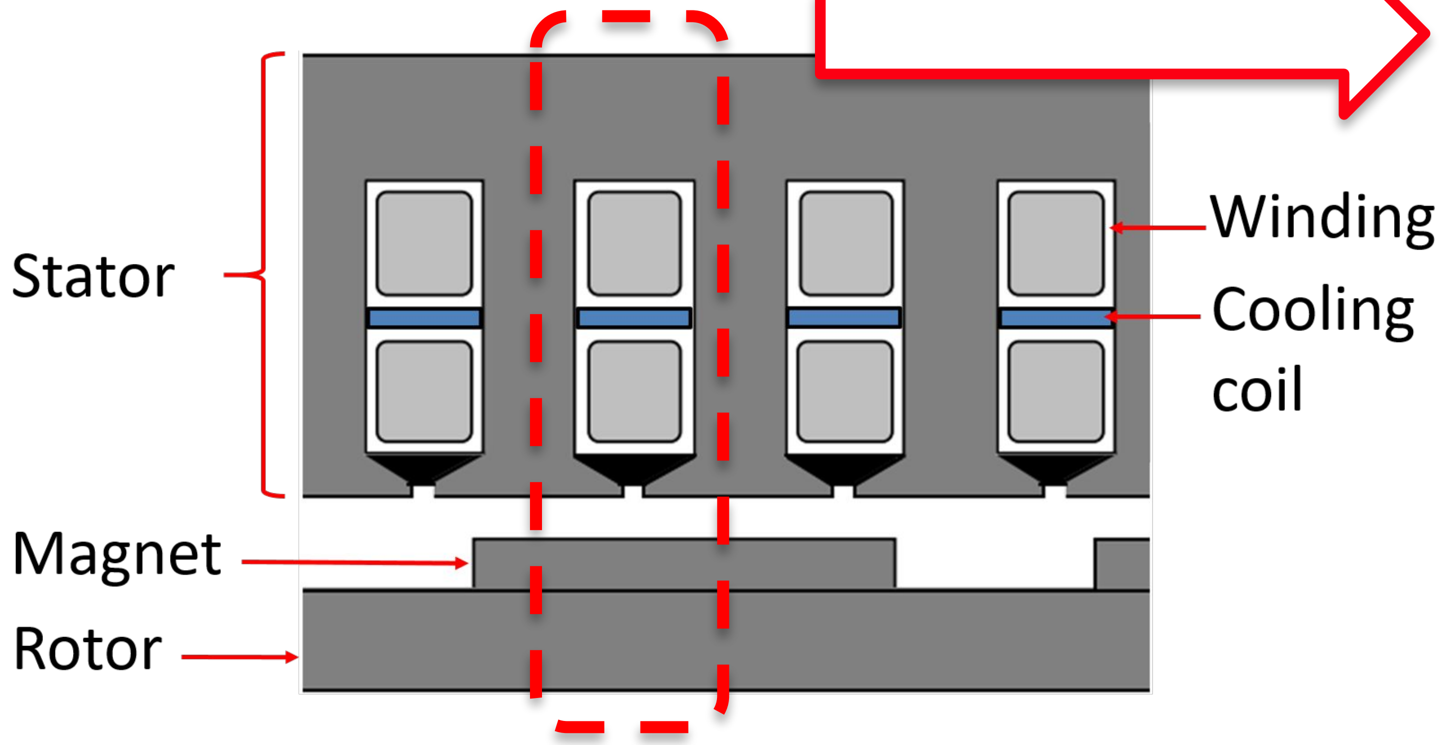
✔ Electrical Model
✔ **Thermal Model**

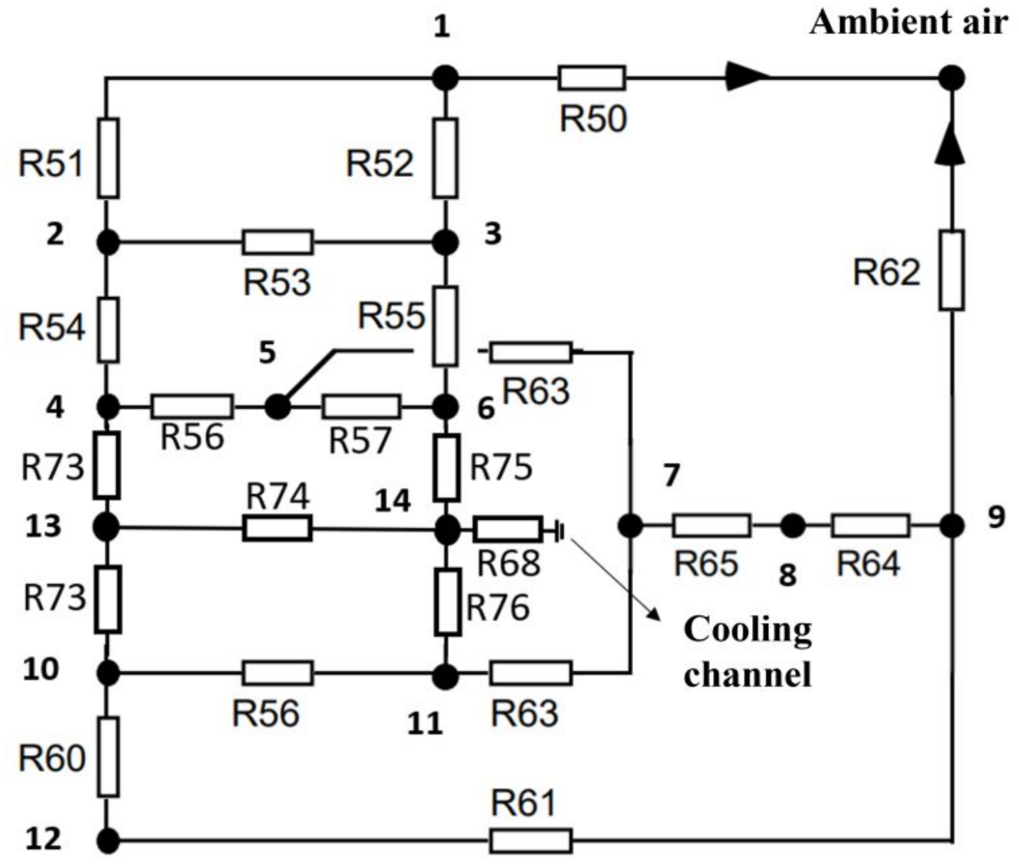
System Model

- Generator:
  - Cooling strategy:
    - Direct cooling;
    - Water forced convection;
    - Cooling coils;
    - External dry coolers.
  - Geometric parameters;
  - Losses (copper, hysteresis, eddy current, friction and windage);
  - Temperatures – lumped parameter model (thermal resistances).

✔ Electrical Model
✔ <u>Thermal Model</u>



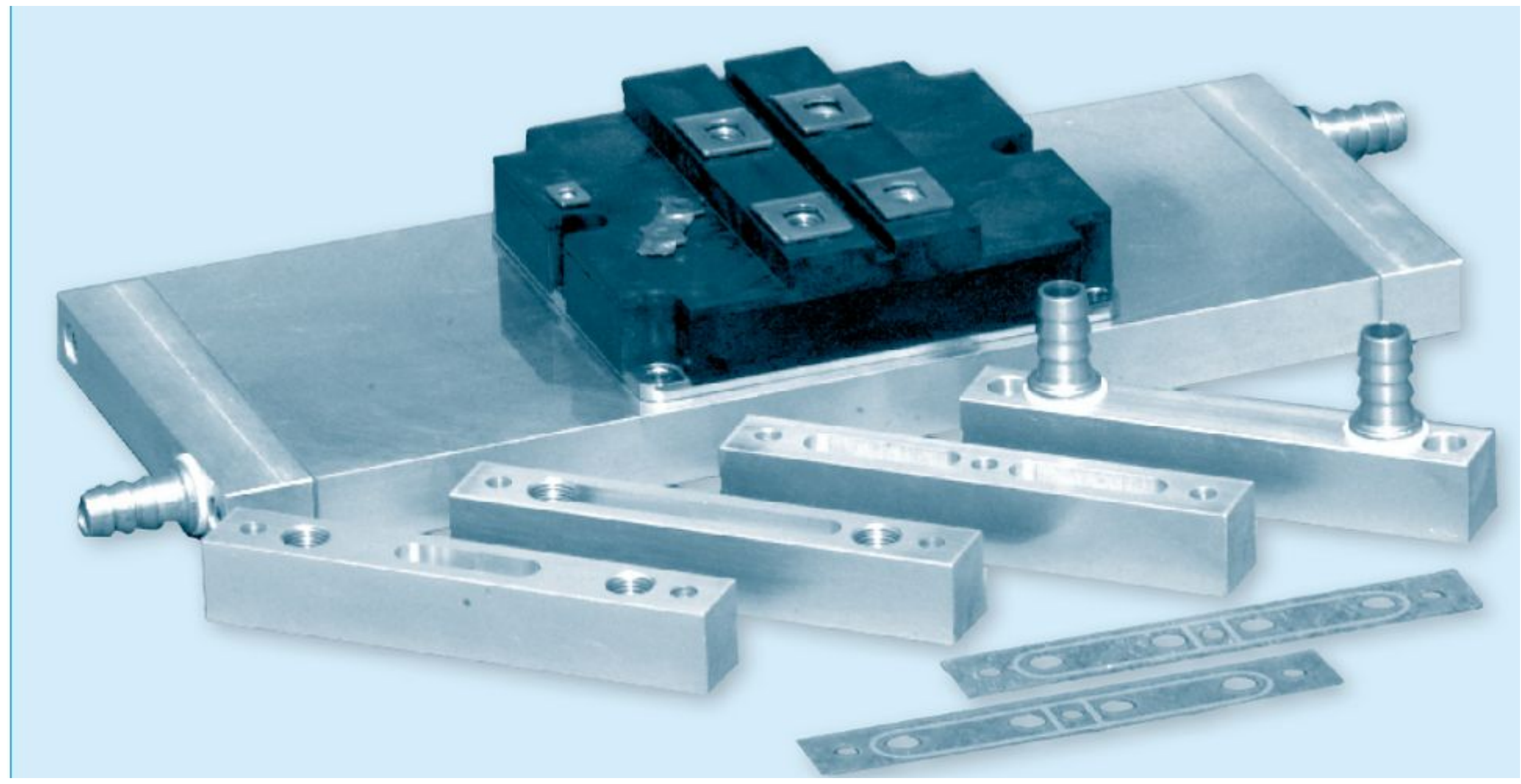


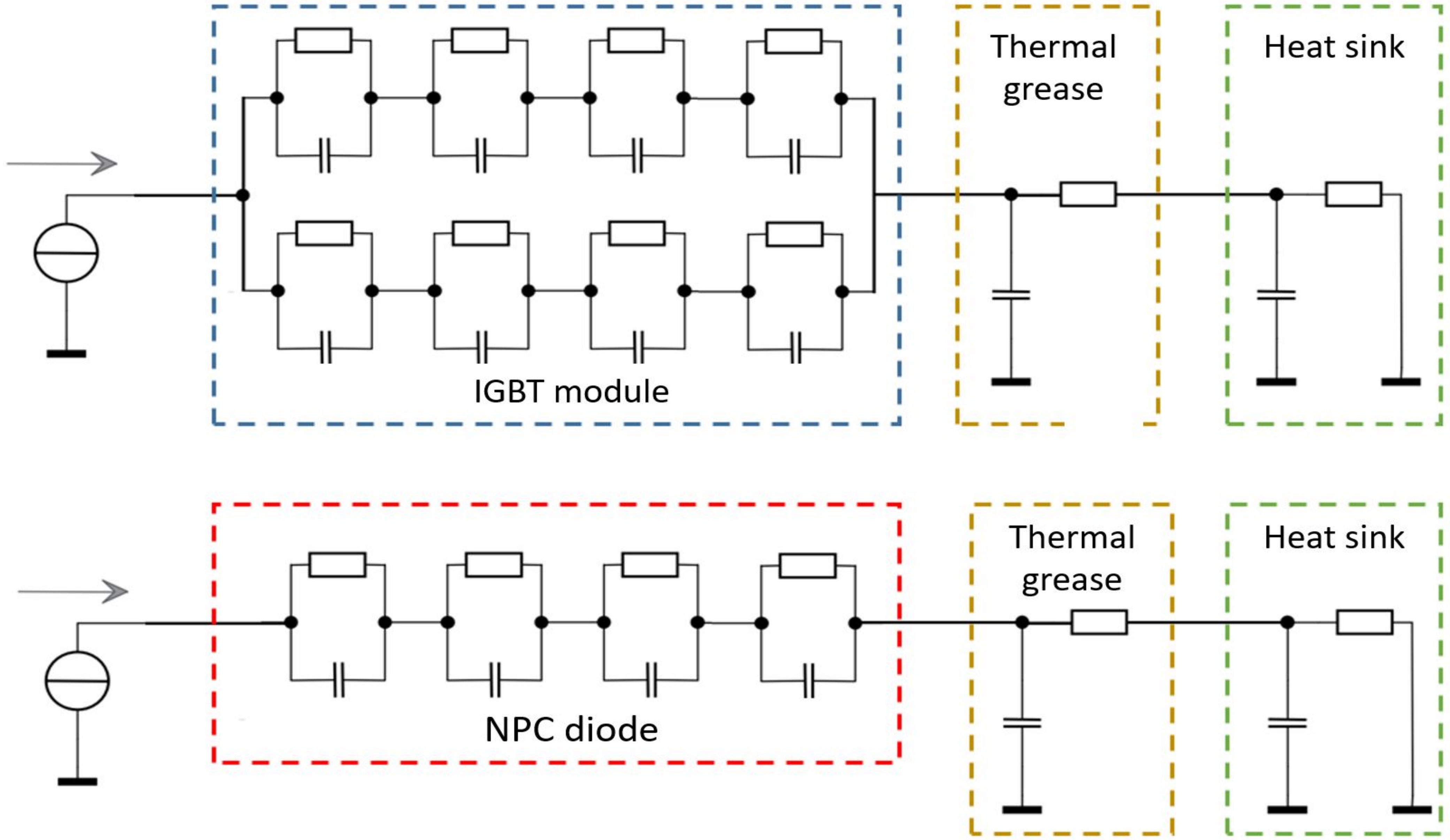


System Model

- Converter:
  - Cooling strategy:
    - Heat sink for power modules;
    - External dry coolers.
  - Commercial device information and geometric parameters;
  - Losses (conduction and switching models);
  - Temperatures – Foster and Cauer models (thermal impedances: RC lumps).
- Thermal Circuit:

✔ **Electrical Model**
✔ **<u>Thermal Model</u>**





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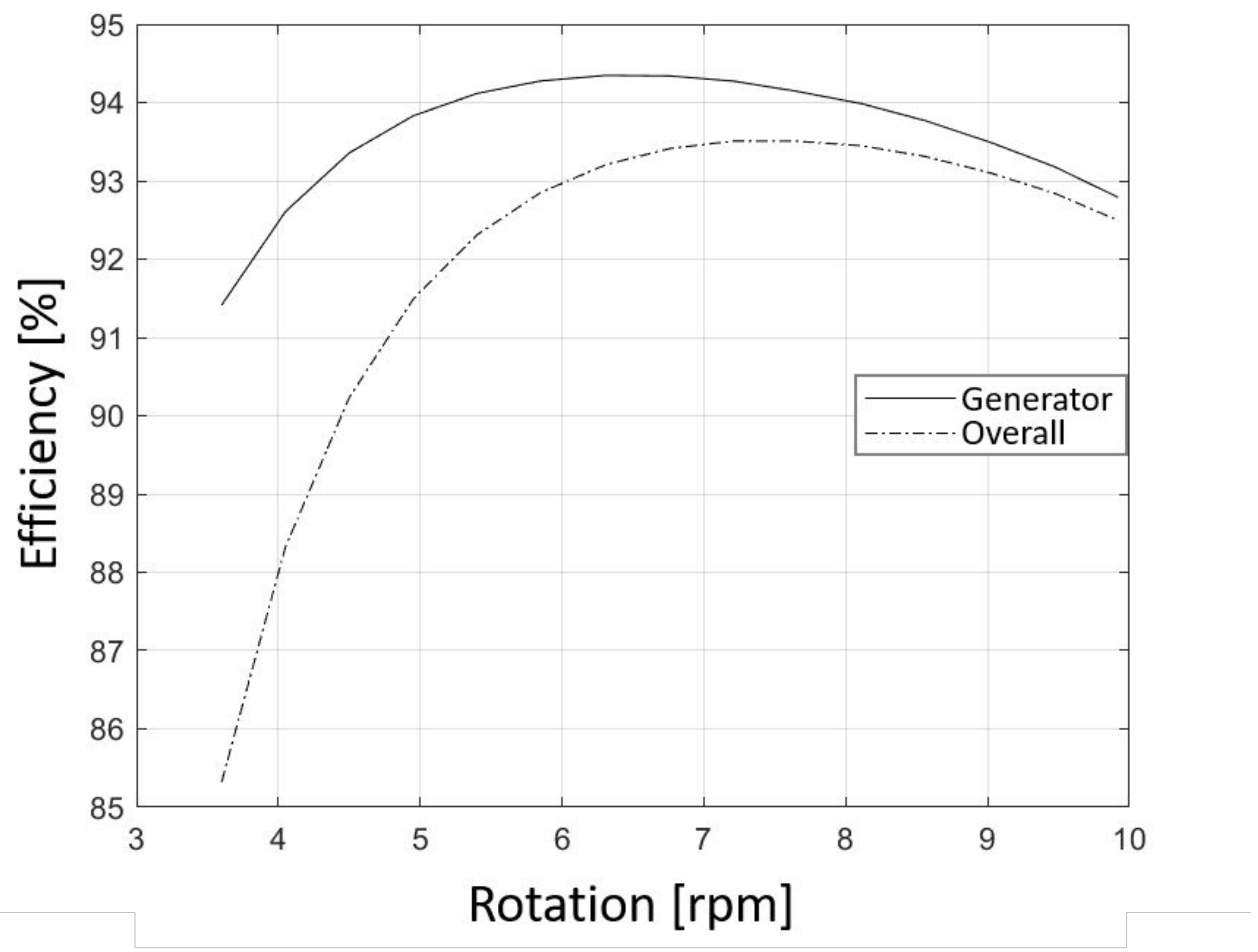
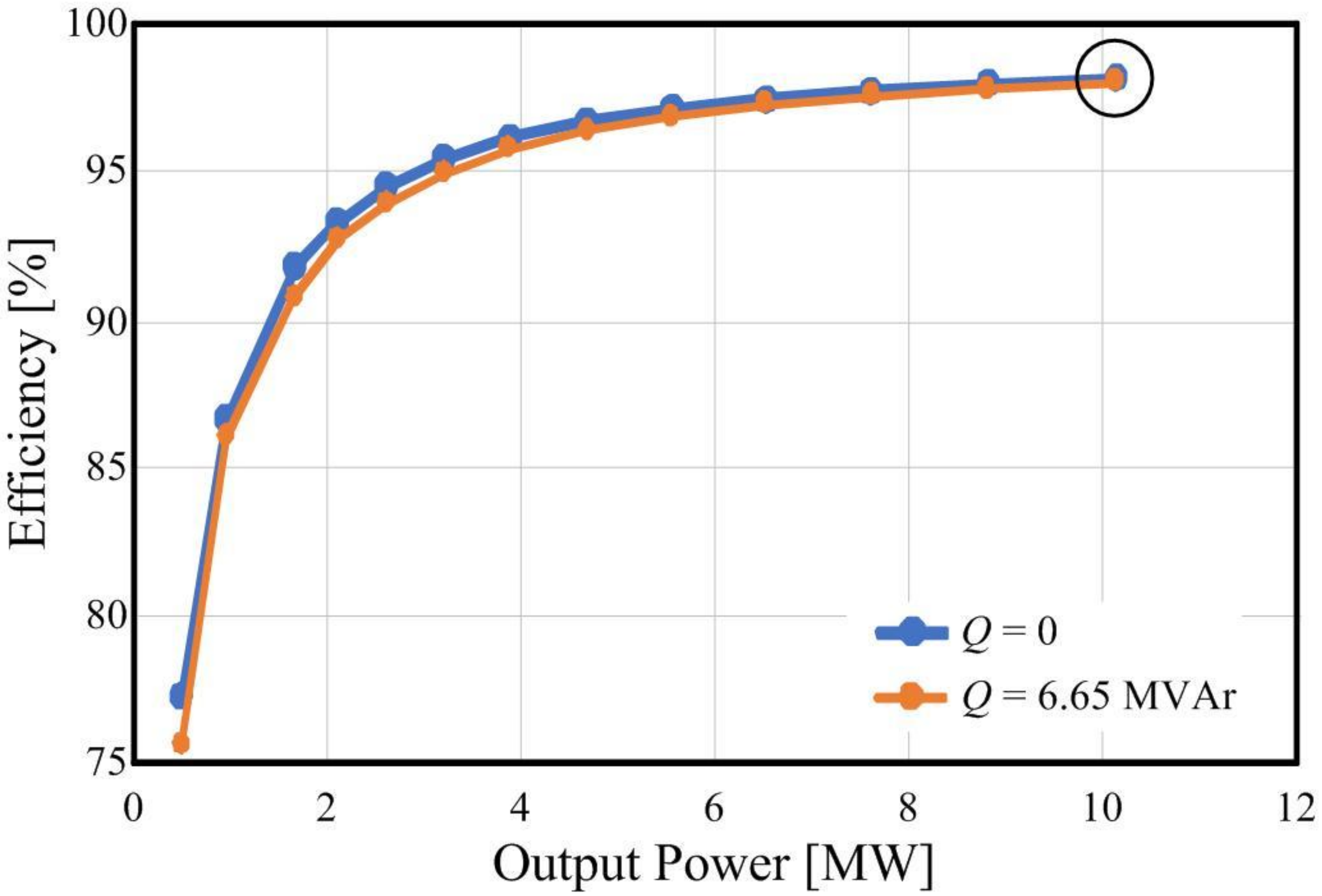
System Model

- Generator:
  - ❑ Rated condition (10 rpm)
  - ❑ Eletric power: 10 MW
  - ❑ <u>Efficiency: 93%</u>



- Converter:
  - ❑ Rated condition (10 rpm)
  - ❑ Eletric power: 10 MW
  - ❑ <u>Efficiency: 98%</u>



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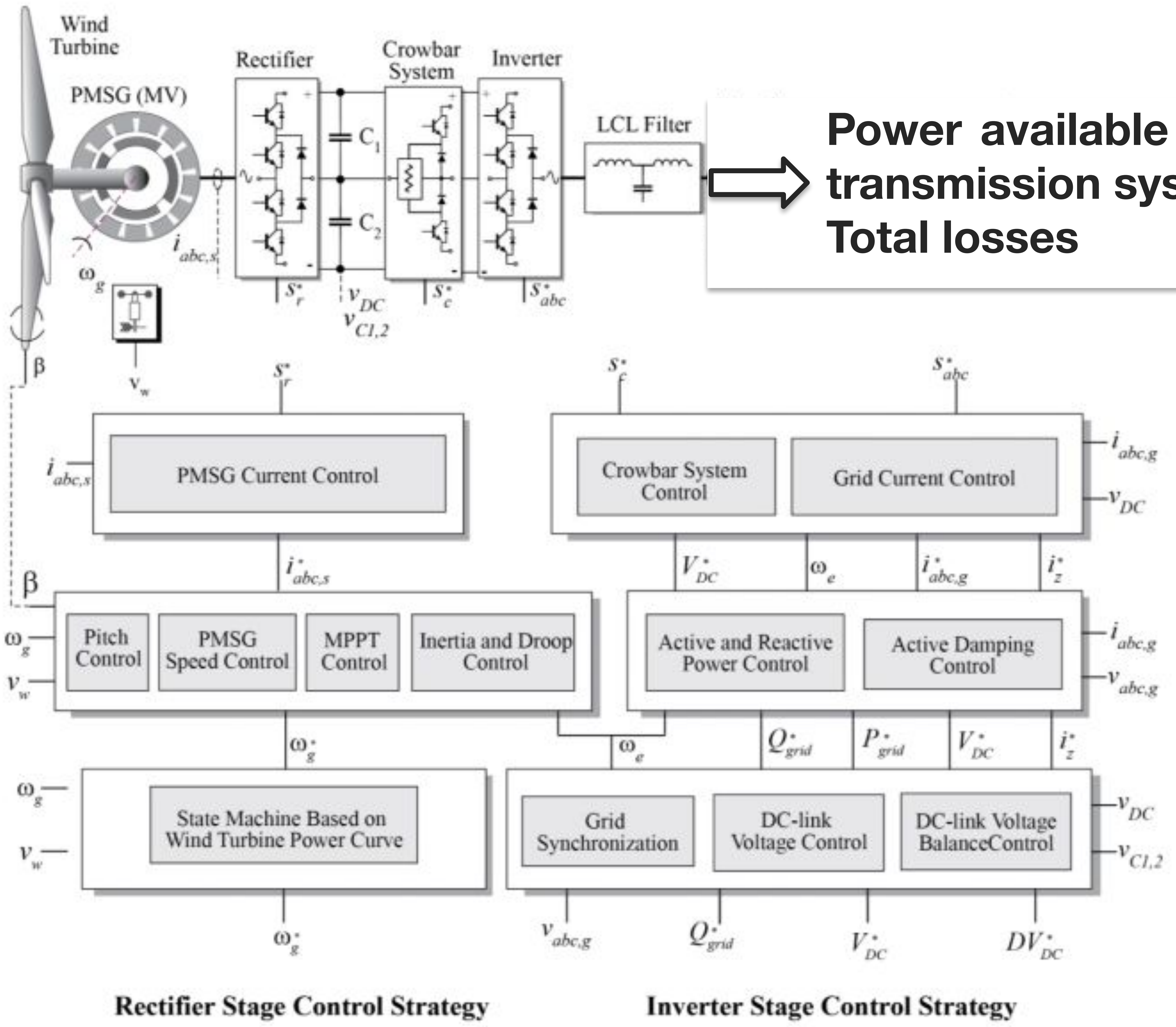
System Model + System Control

- **Input:** Wind Profile
- **Output:** Power available on the FPSO
- **Ancillary services (extra):** active power, reactive power
- Mechanical and electrical variable control



Power available to the transmission system
Total losses

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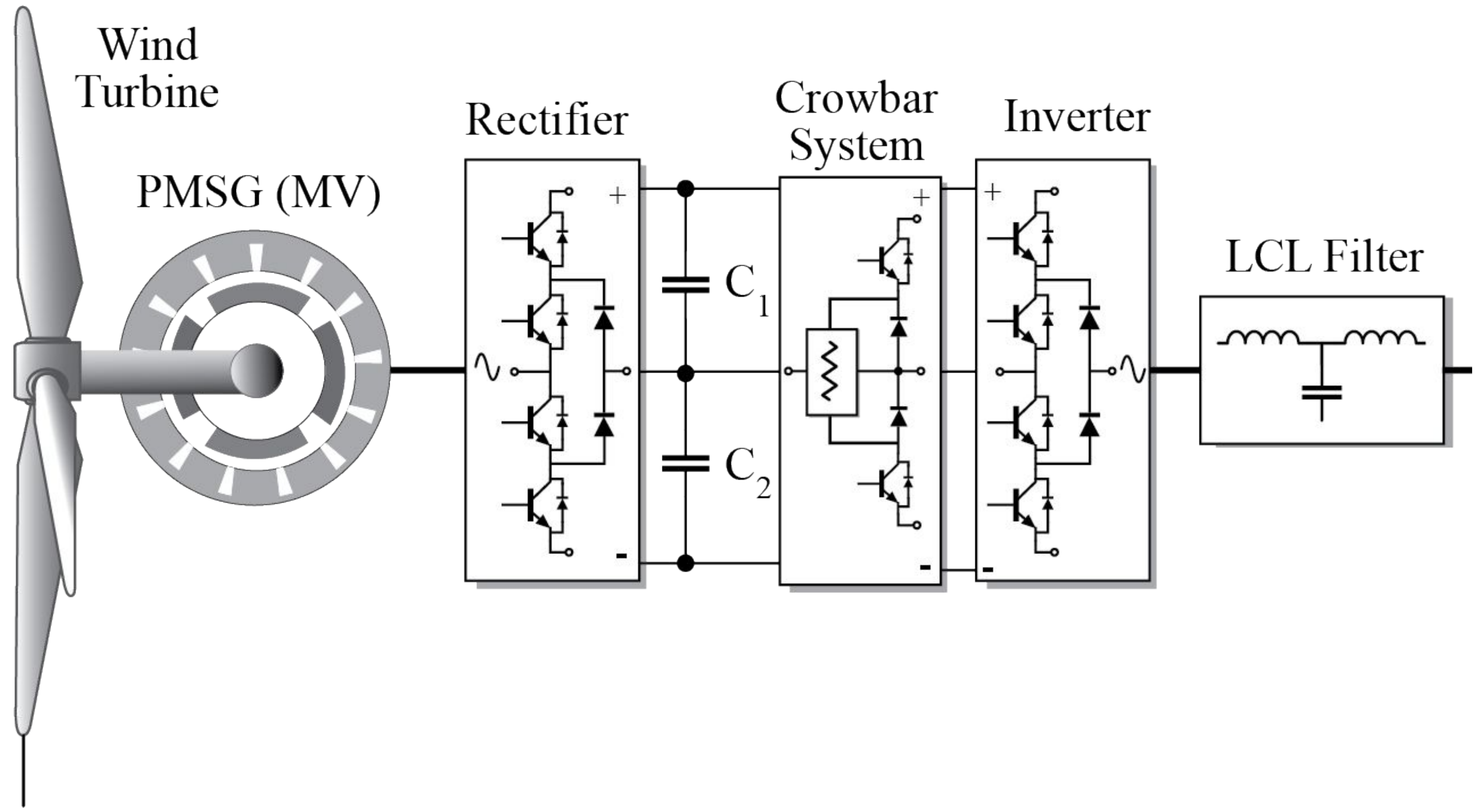
Wind Energy Conversion System (WECS)

- Recommended solution:
  - Direct drive;
  - PMSG;
  - Back-to-back converter (three-level NPC) - two in parallel;
  - Medium voltage.
  - Ability to supply active power (as a function of wind - intermittent source)
  - Ability to supply reactive power.

Wind profile



▪Power (active and recative) available to the transmission system
▪Total losses

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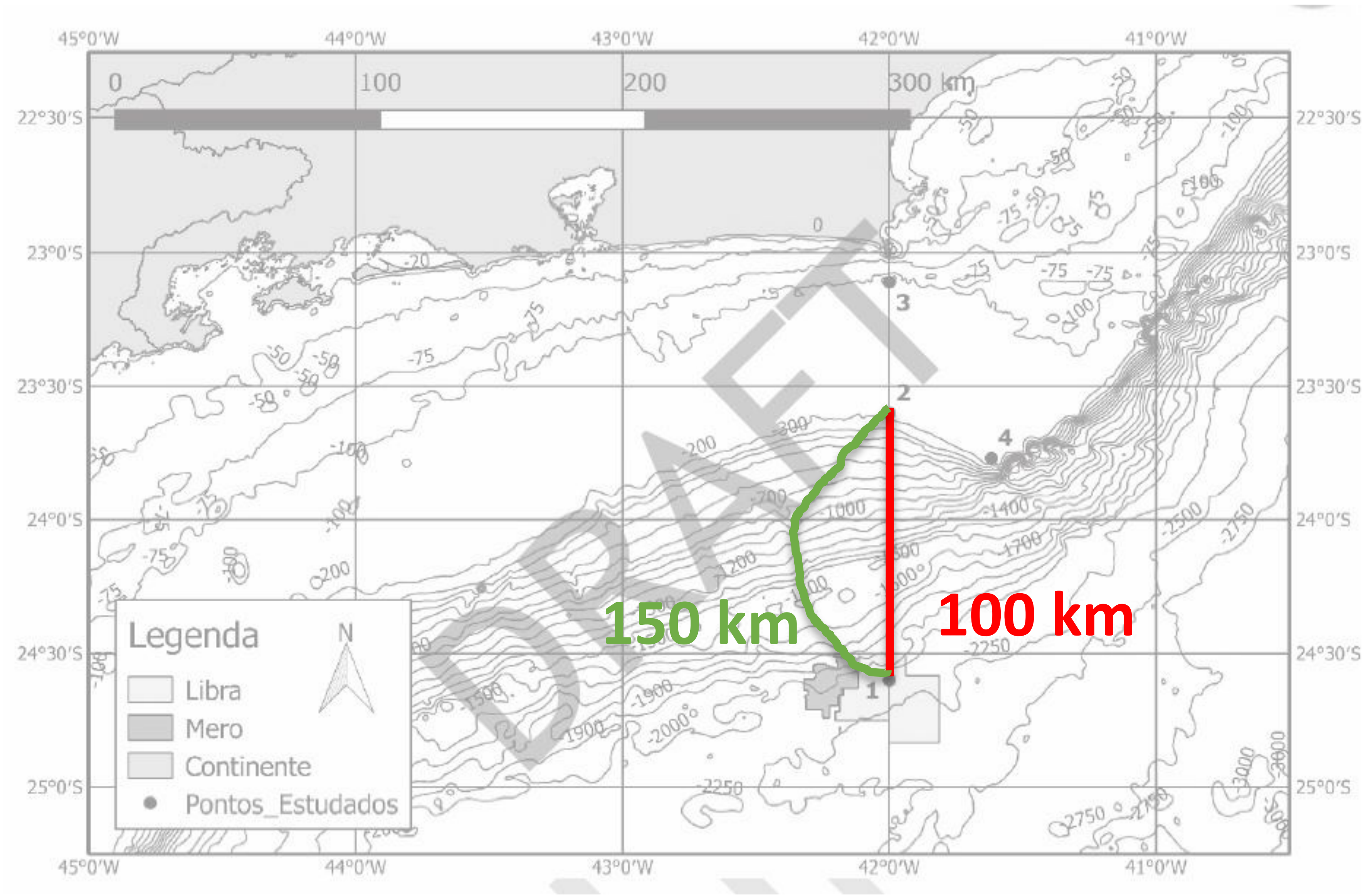
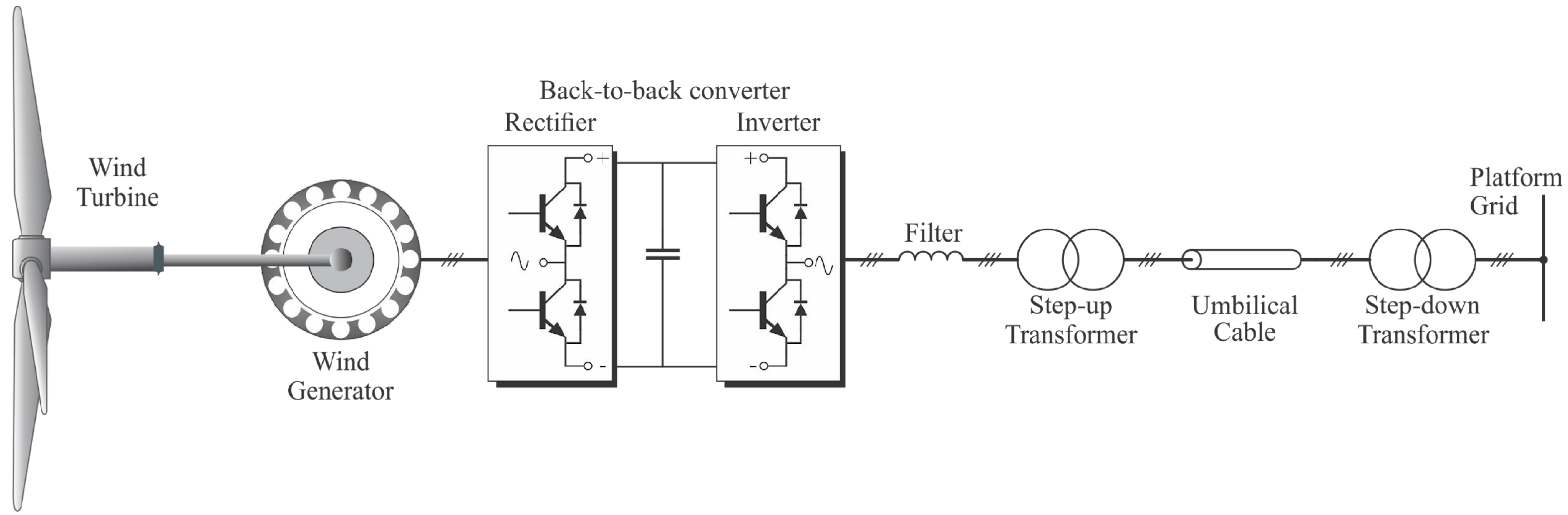
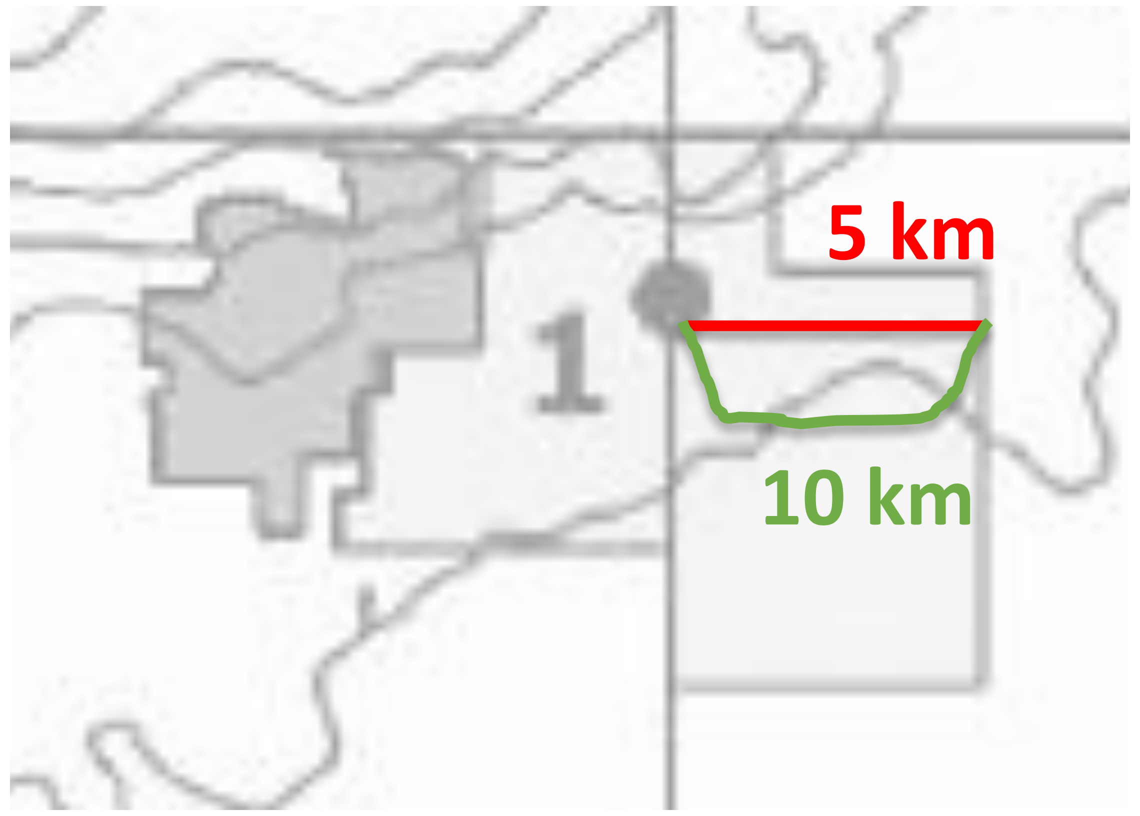
Subsea Umbilical Cable Transmission System

- Two cases:
  - An umbilical of 10 km (WT close to the FPSO);
  - An umbilical of 150 km km (WT close to the cost).
- Design based on:
  - Calculation of ampacity through thermal analysis;
  - Calculation of the maximum current during short-circuit;
  - Calculation of losses and voltage drop by power flow analysis.







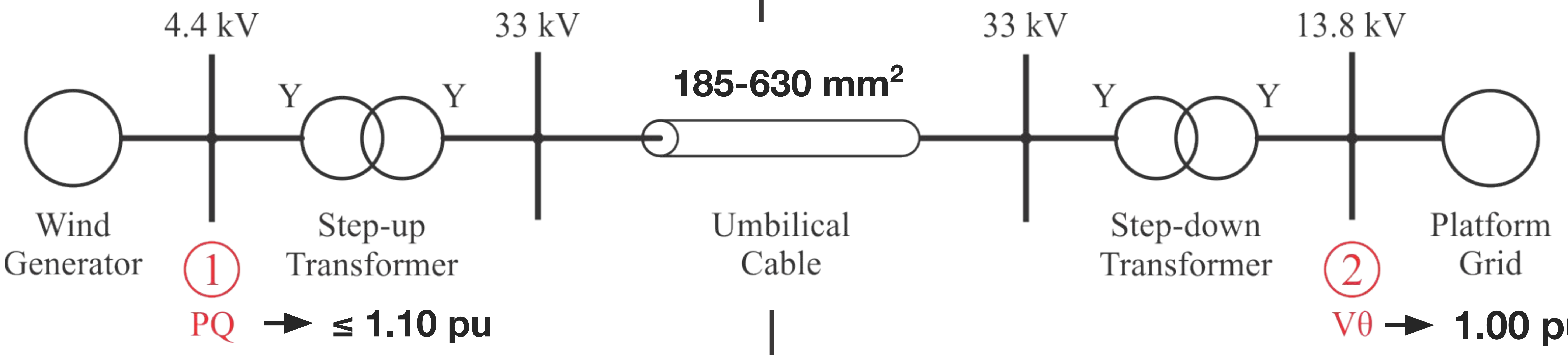
Subsea Umbilical Cable Transmission System – Power flow analysis

- Studied – 30 kV – 42 KV
- Chosen – 33 kV – 36 kV → **great point (185 mm²)**

From ampacity and short-circuit analysis

185-630 mm²

0 ≤ P1 ≤ 10 MW
0 ≤ S1 ≤ 15 MVA



PQ → **≤ 1.10 pu**

Vθ → **1.00 pu**

Cost
Losses
Reactive power
} **Minimum loss optimization**

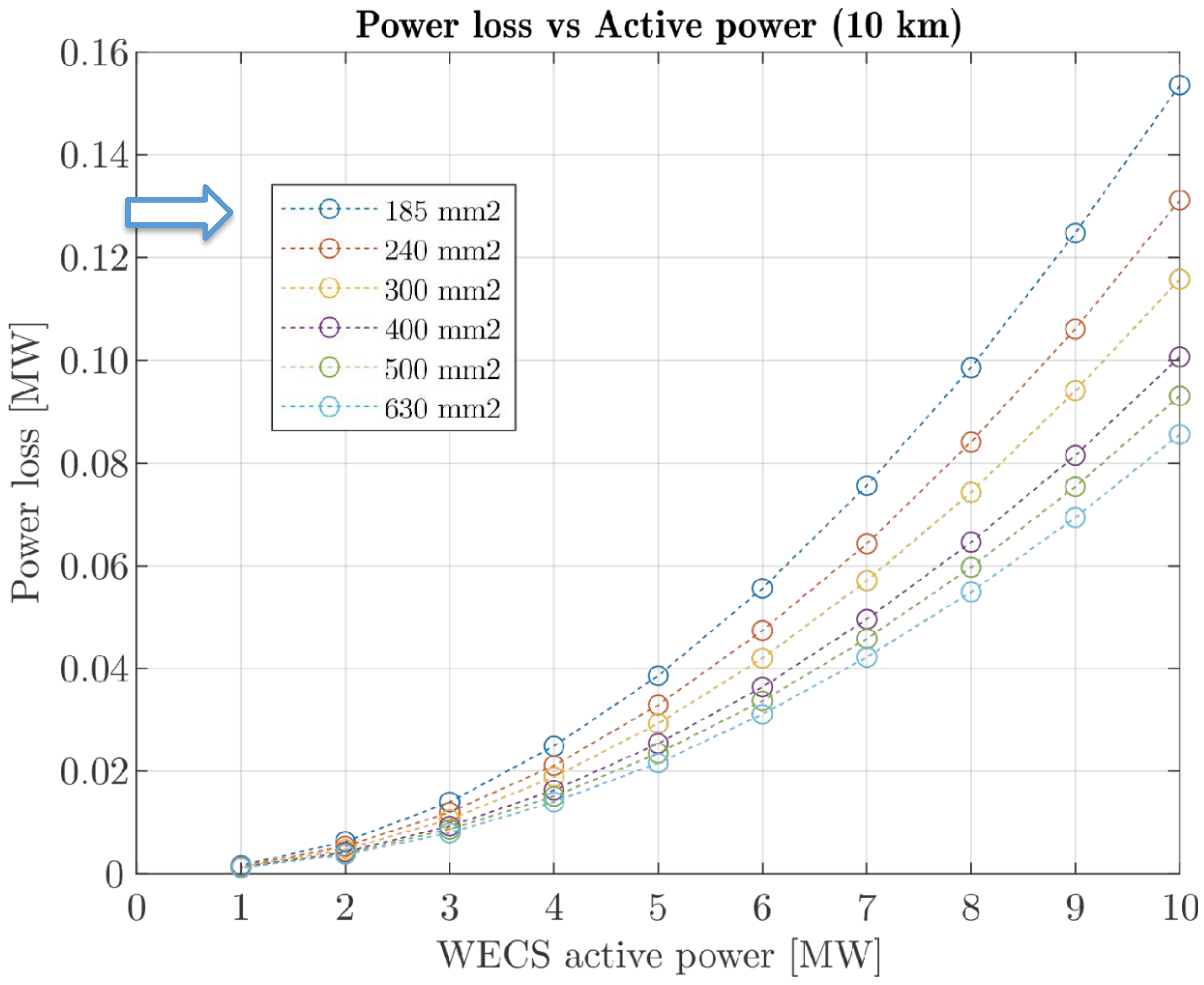
- Umbilical cables with insulation of 45 kV.
- Objective:

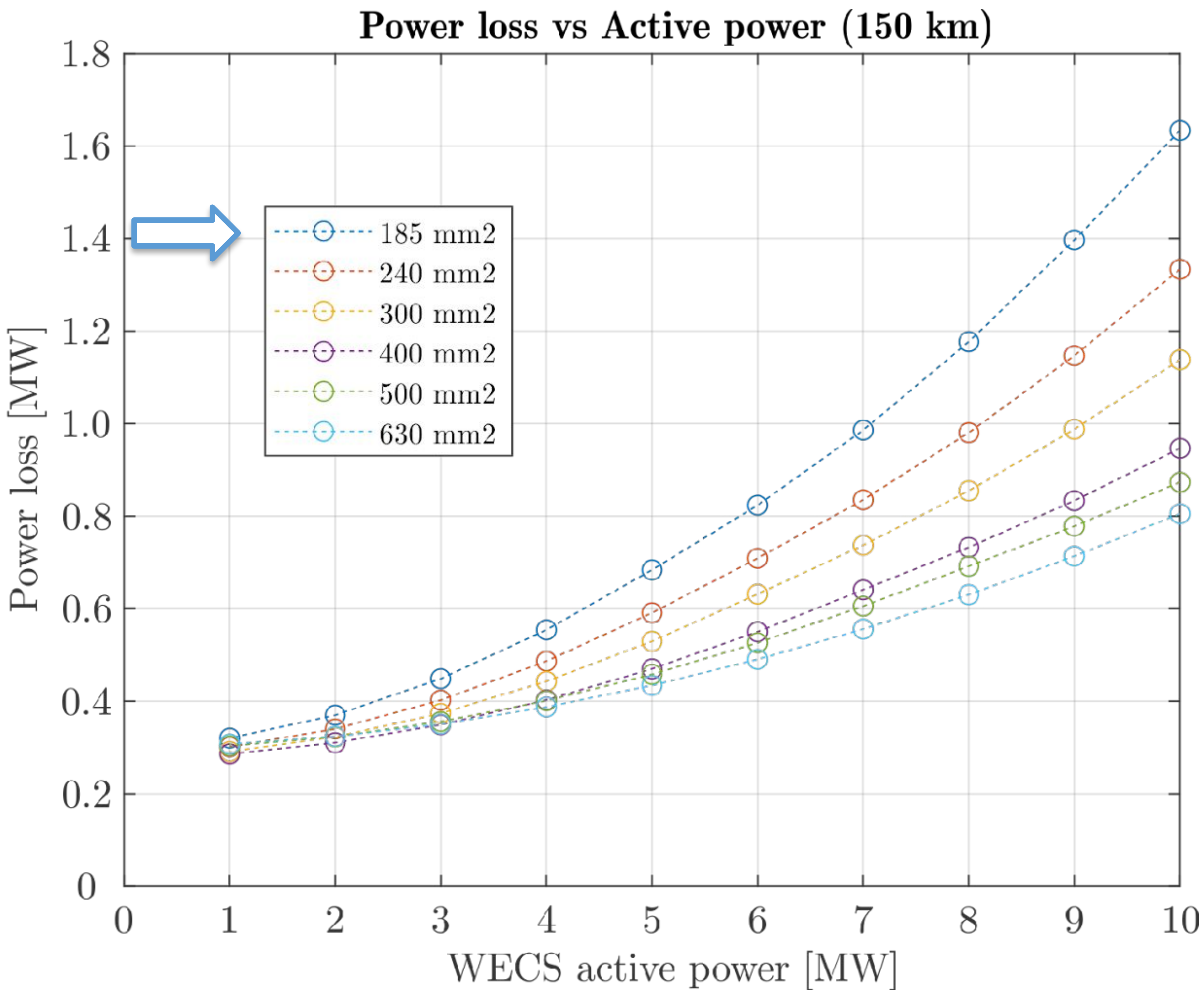
$$\text{minimize} \quad P_{wecs} - P_{fpso} = f(P_{wecs}, Q_{wecs}, V_{fpso}),$$

$$\text{subject to} \begin{cases} P_{wecs} \leq S_{wecs} \leq S_{max} \\ 0.9 \text{ pu} \leq V_{wecs} \leq 1.1 \text{ pu} \\ V_{fpso} = 1.0 \text{ pu} \end{cases}$$

Subsea Umbilical Cable Transmission System – Power flow results

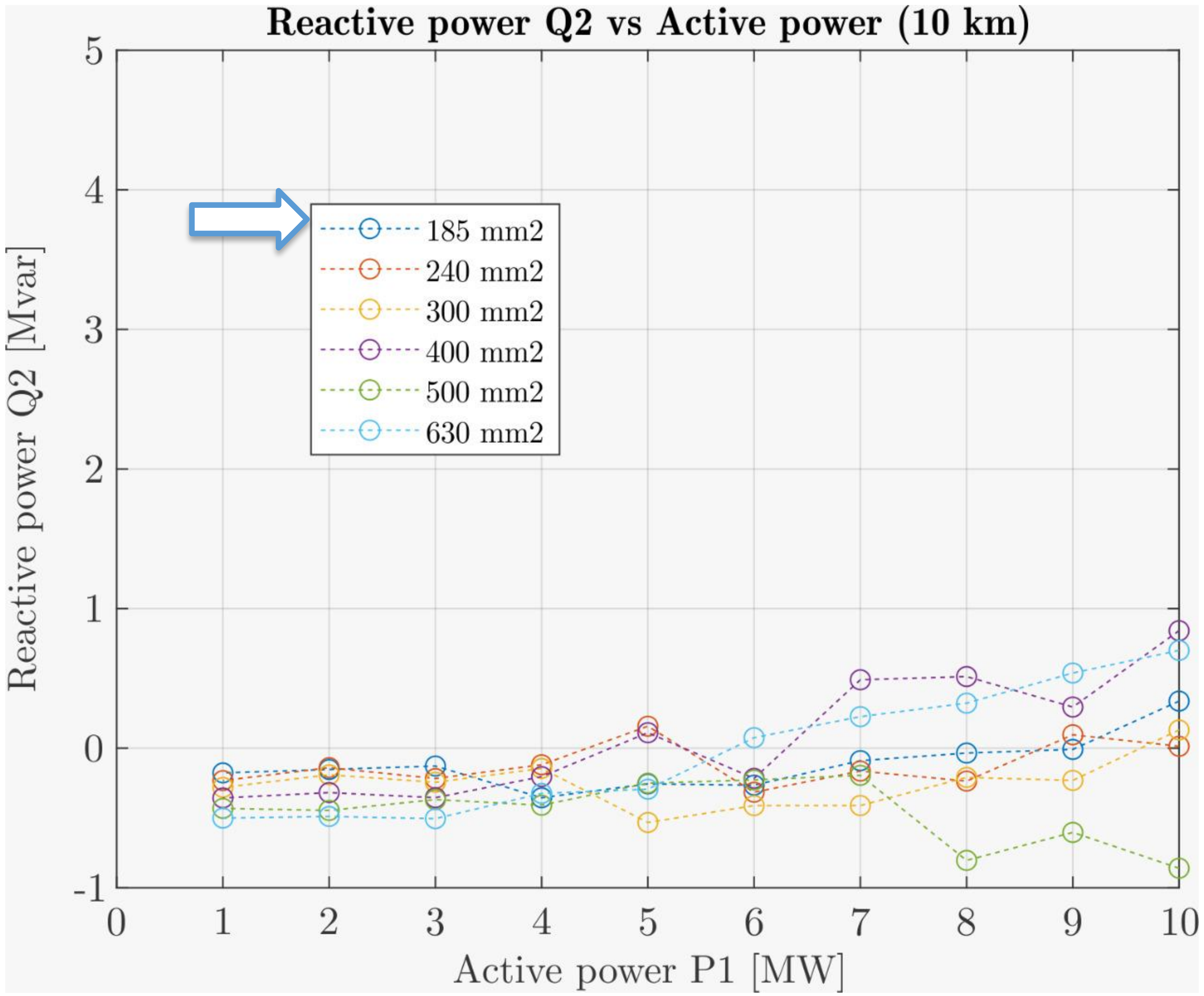
- Minimum loss optimization (for 10 and 150 km):

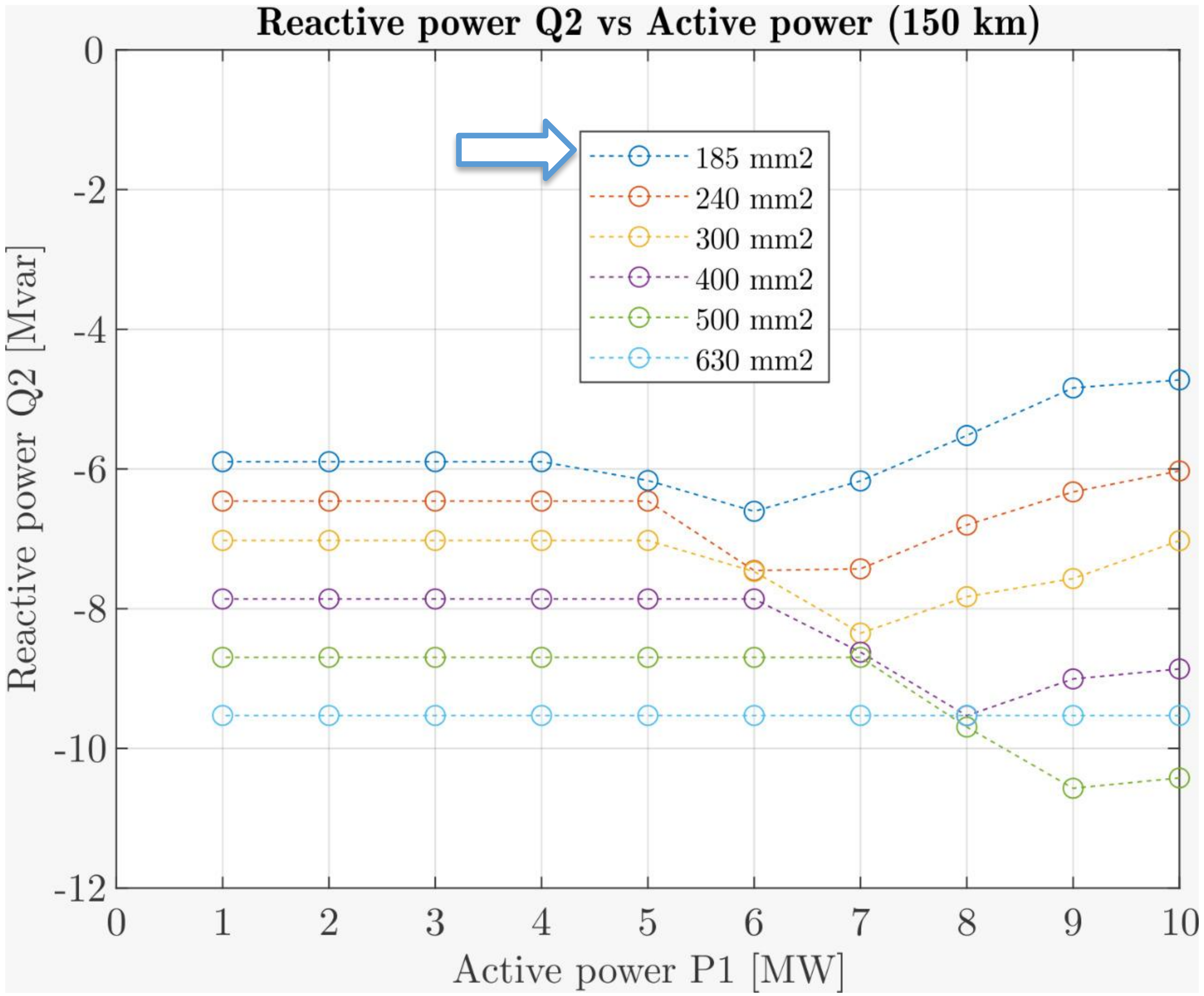




Subsea Umbilical Cable Transmission System – Power flow results

- Minimum loss optimization (for 10 and 150 km):





Wind Generation System Simulations

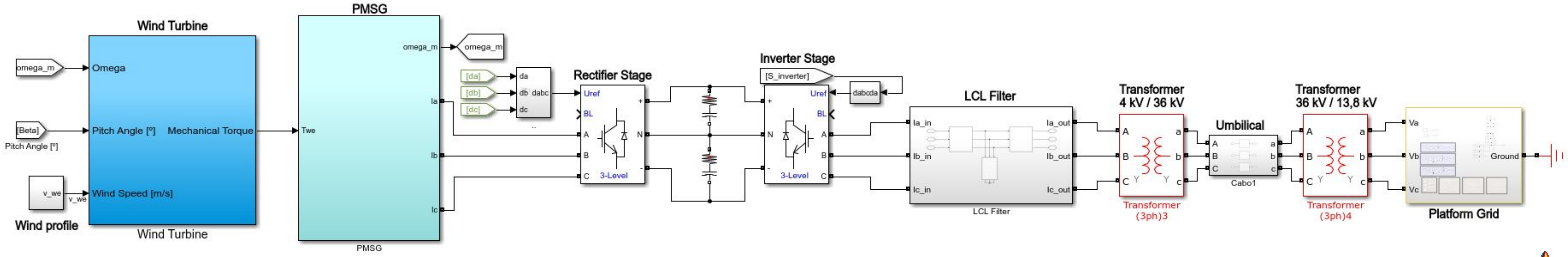
- Objectives:
  - ❑ Analyze the steady-state operation;
  - ❑ Analyze low frequency dynamics;
  - ❑ Validate control strategies:
    - Current and voltage control;
    - Speed and Pitch control;
    - Frequency control support;

- 1° Model – Average Model:

✔ Provide a complete model of the wind system for integration with the platform.

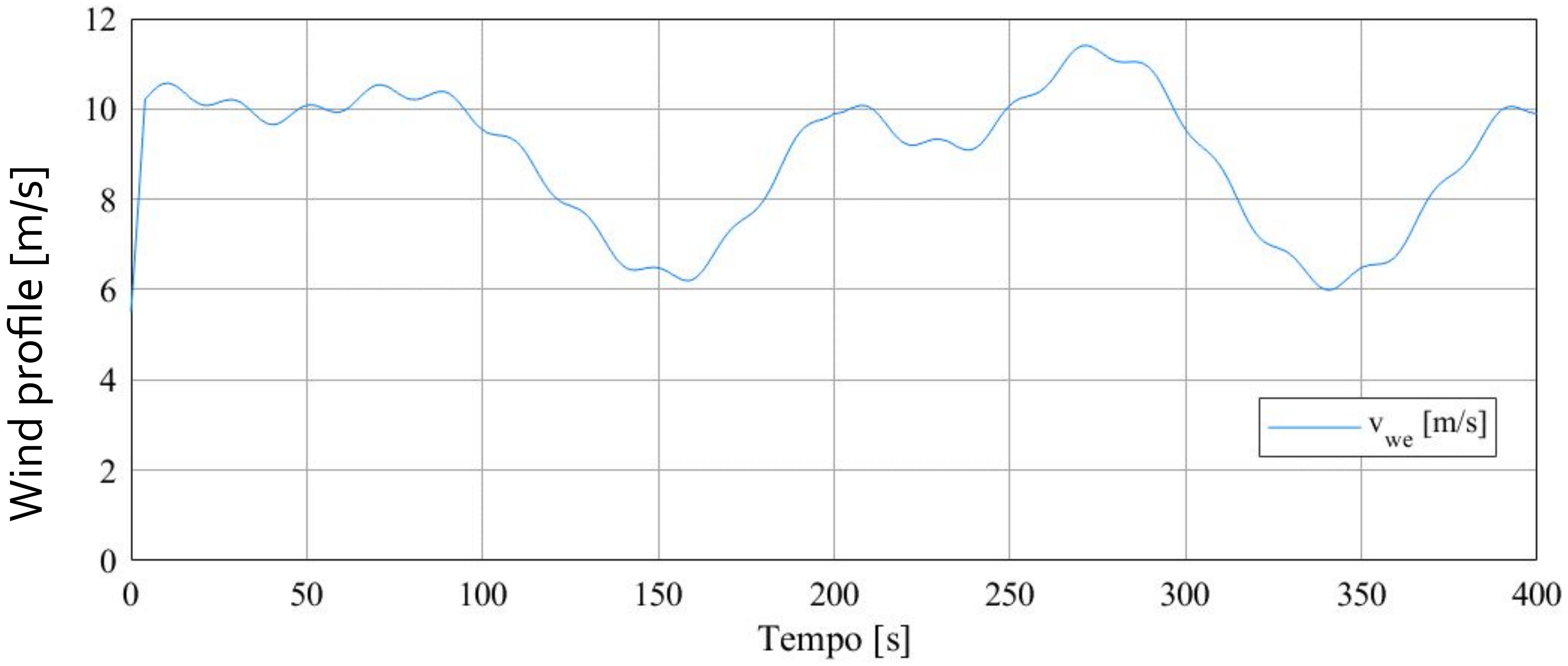
✔ Reduce system simulation time.

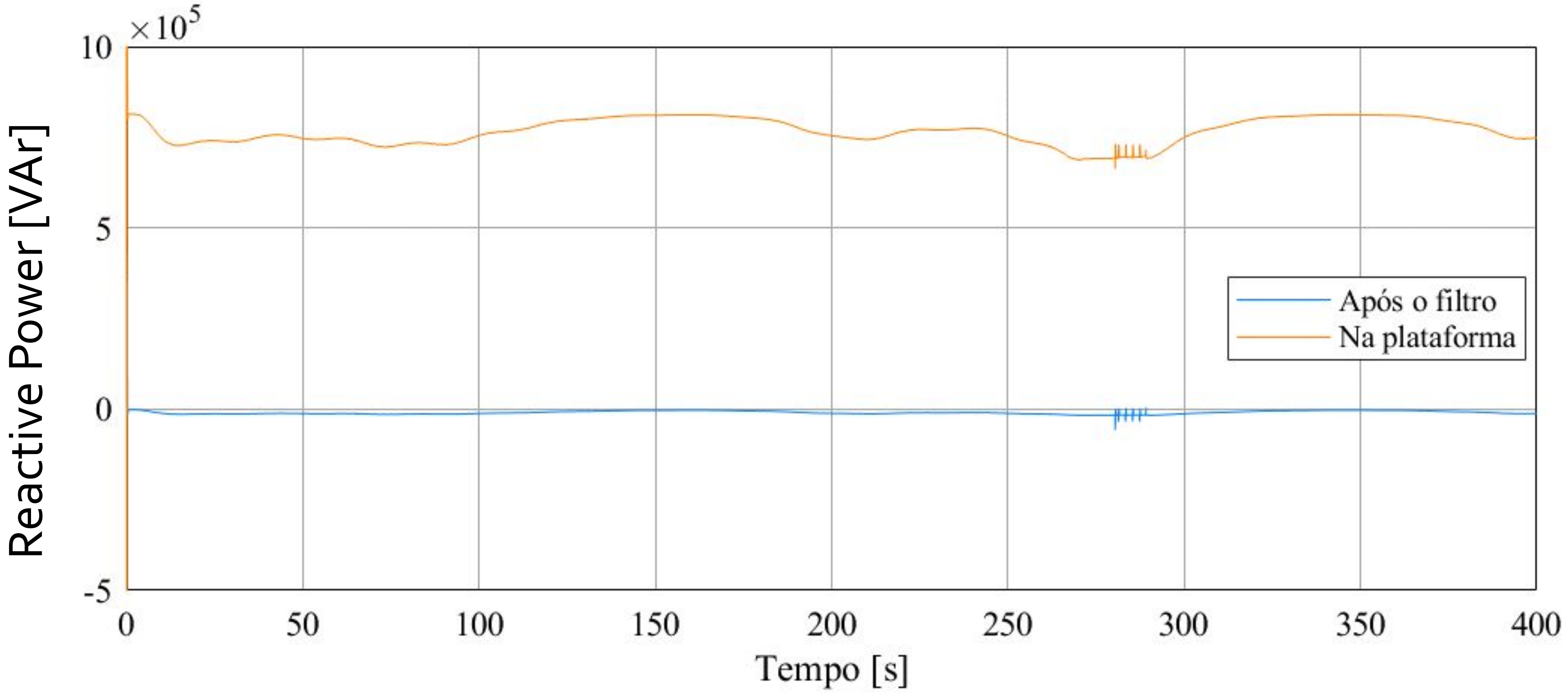
✘ Model does not include the effects of switching the converters.

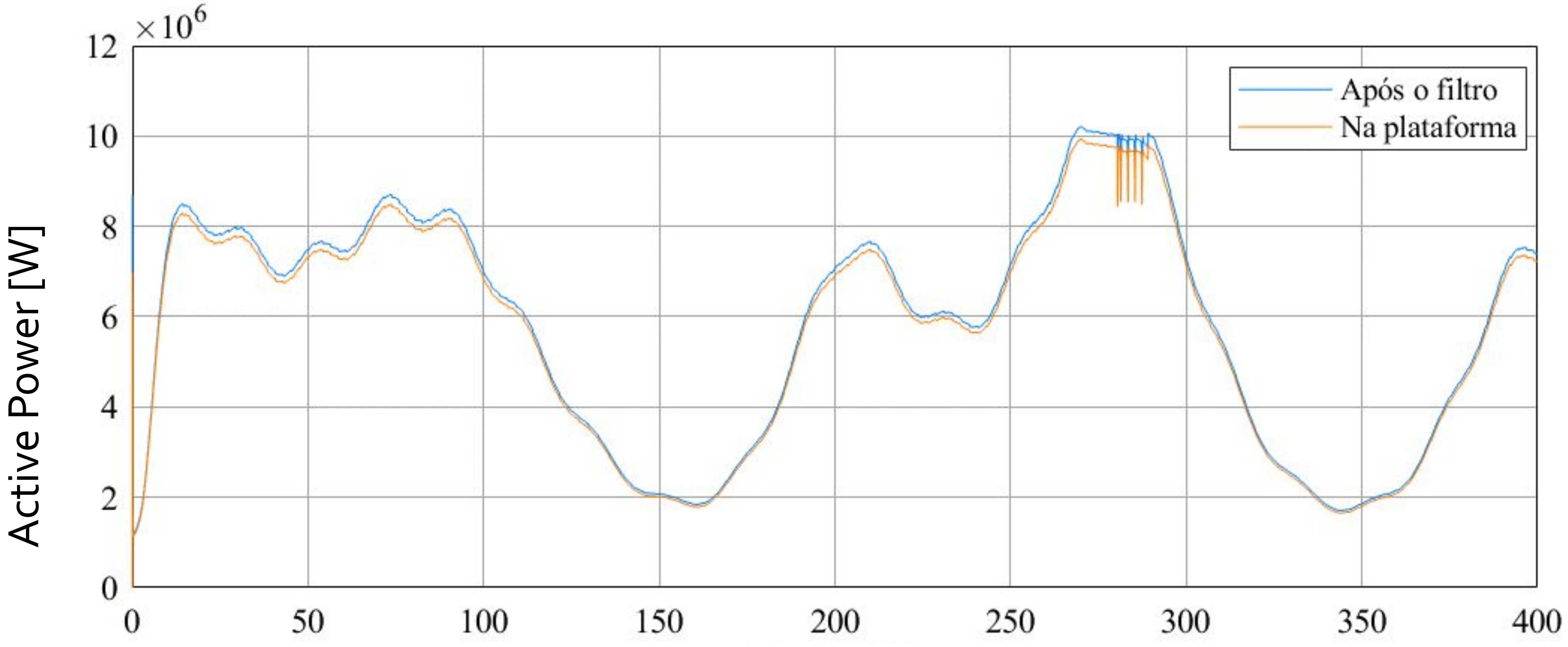


MATLAB® & SIMULINK®

Wind Generation System Simulations – Average Model – 10 km







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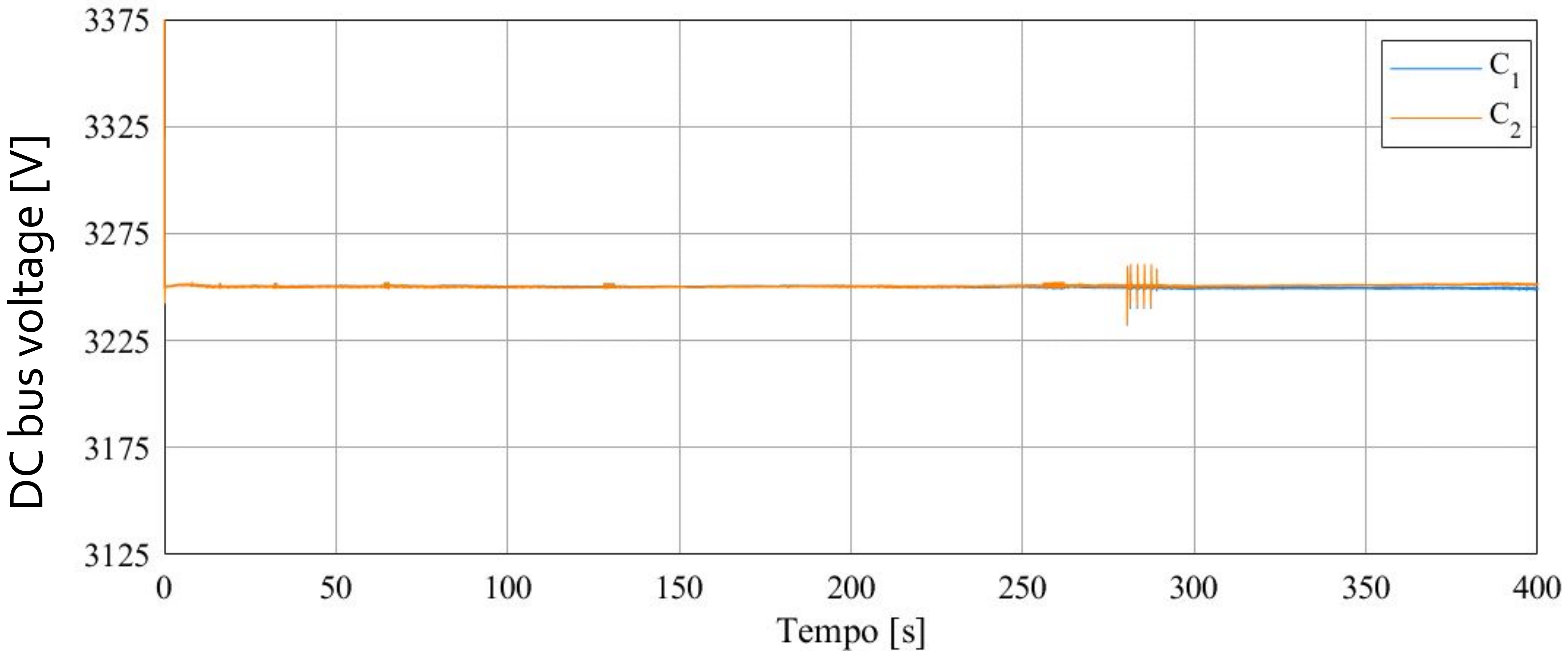
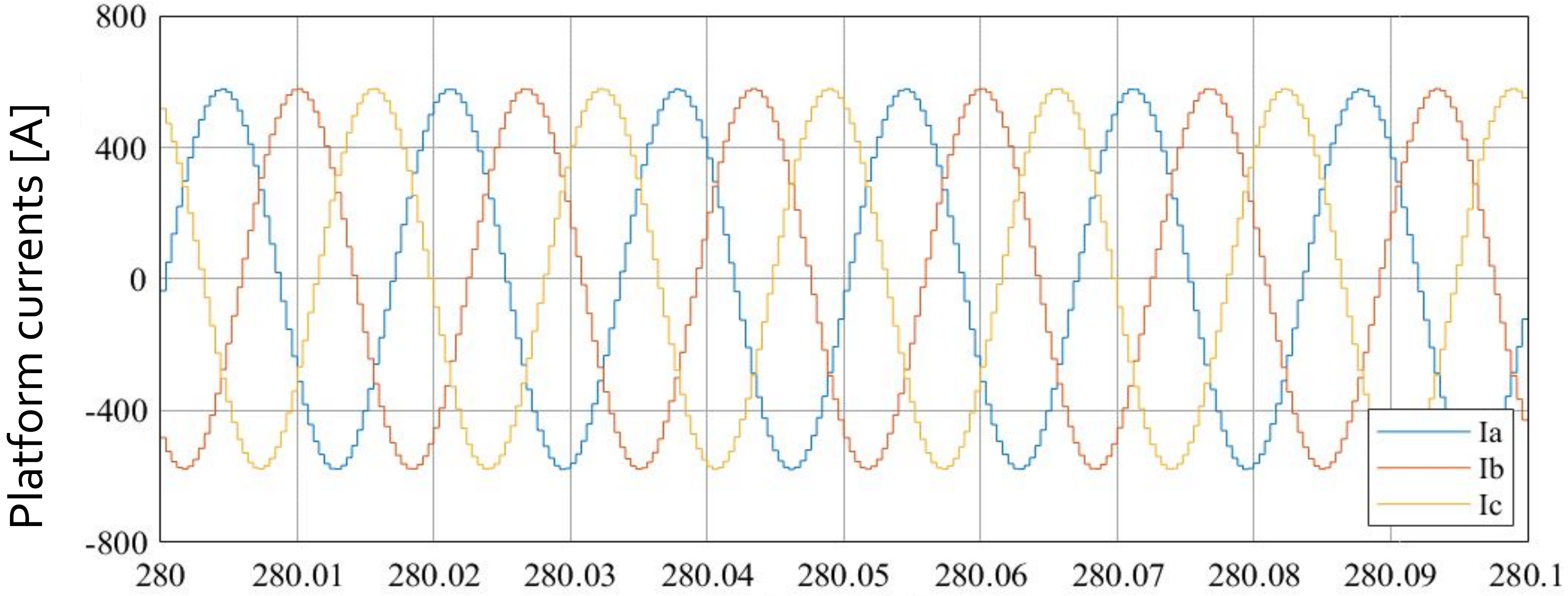
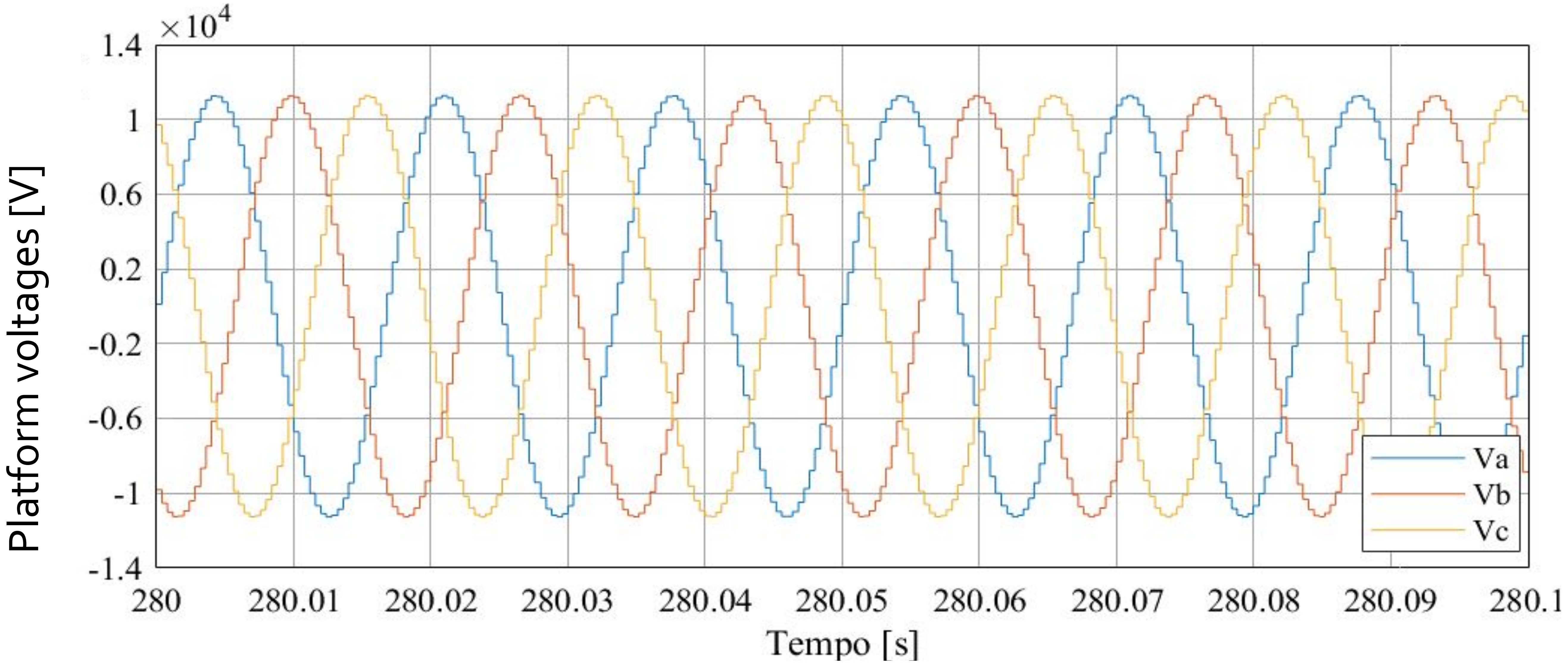
Wind Generation System Simulations – Average Model – 10 km



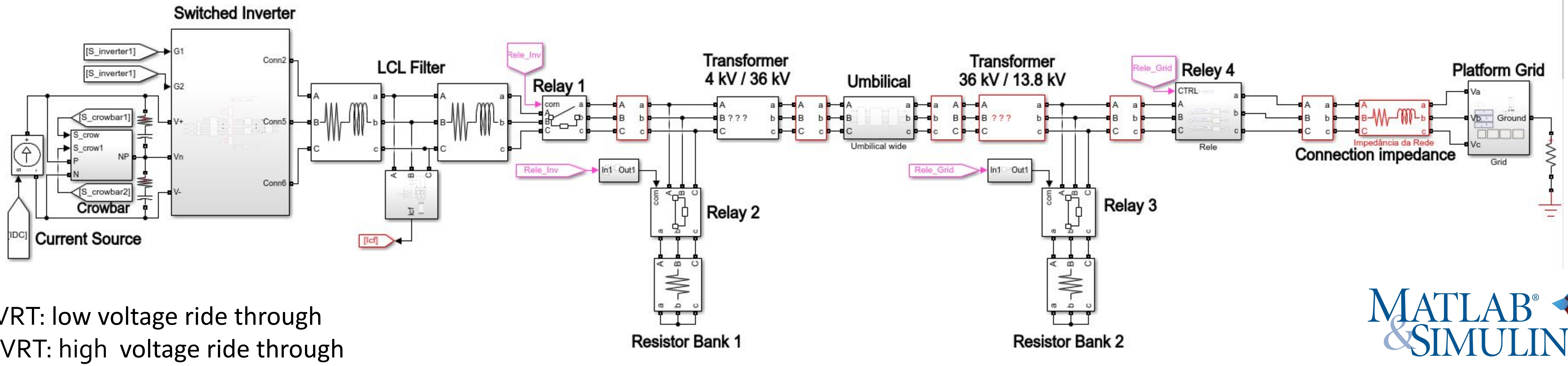




Wind Generation System Simulations

- Objectives:
  - ❑ Analyze the steady-state operation;
  - ❑ Analyze low and high frequency dynamics;
  - ❑ Check the quality of current injected into the platform;
  - ❑ Validate LVRT[1] and HVRT[2] control strategy.

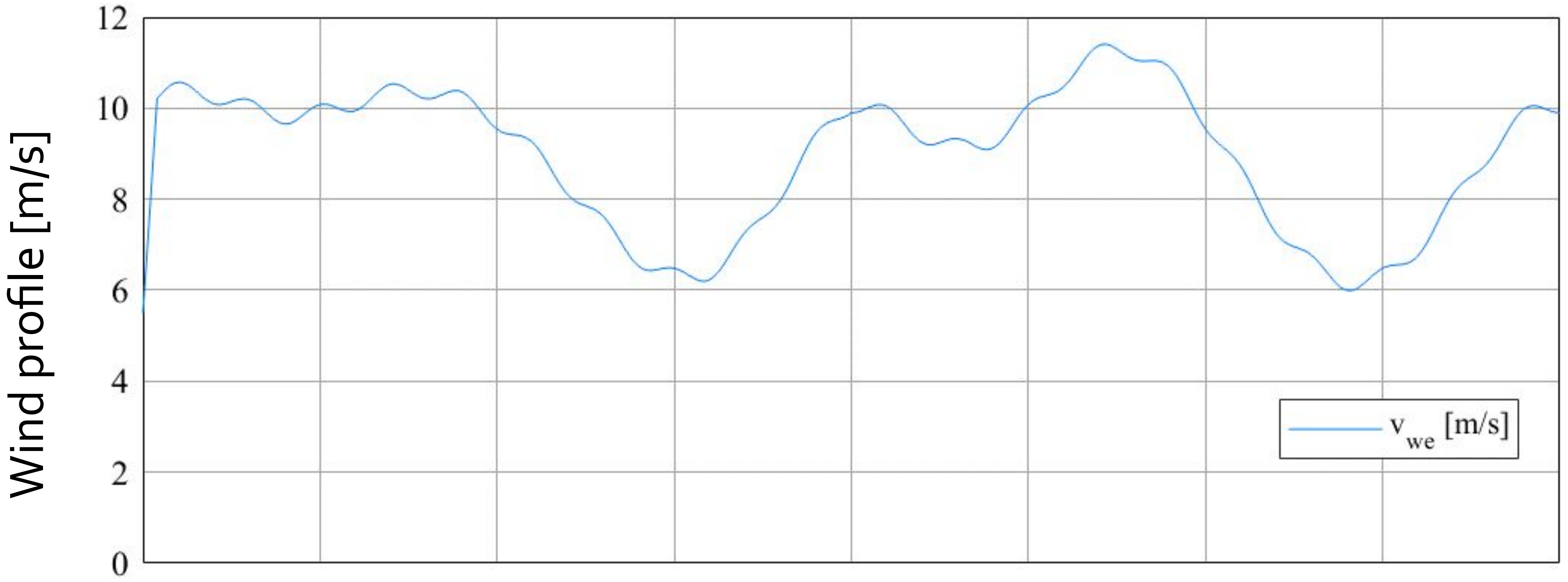
- 2° Model – Inverter Switched Model:
  - ✔ Provide a detailed model of the inverter stage of the wind system for integration with the platform.
  - ✔ Simplify the turbine, generator and rectifier models by a current source.
  - ✔ Reduce system simulation time.

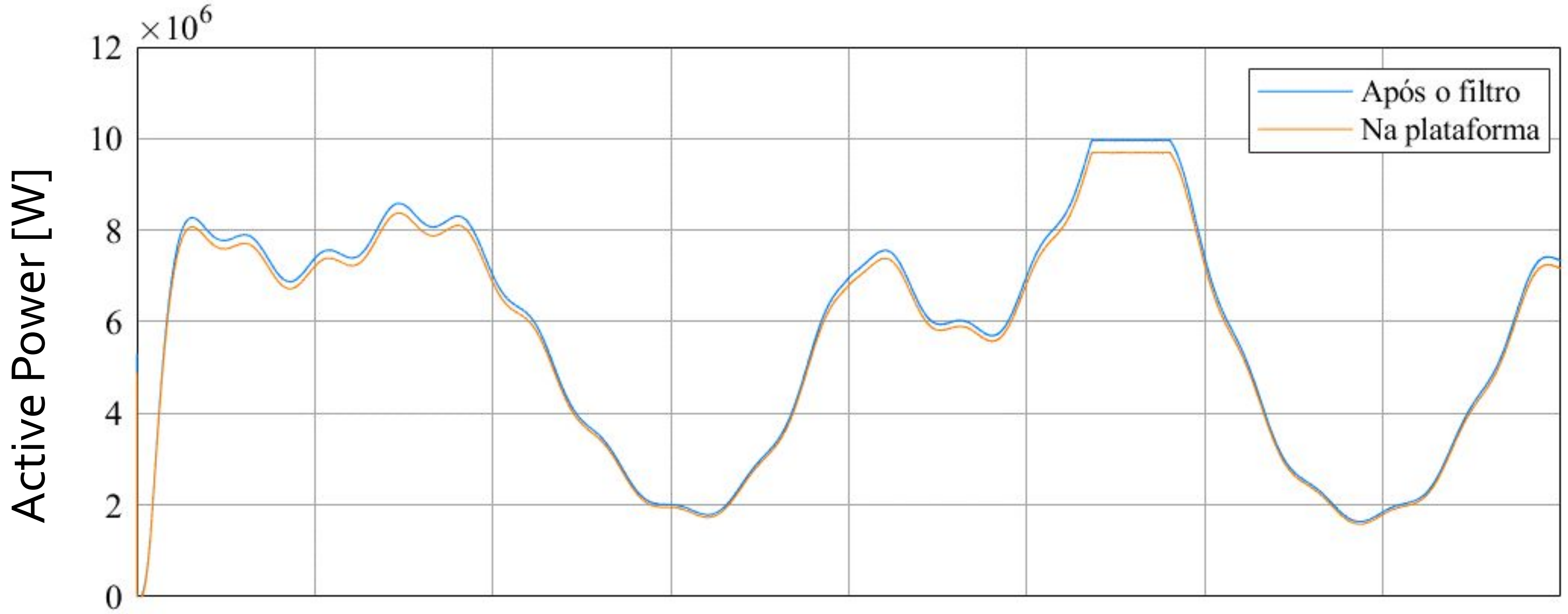


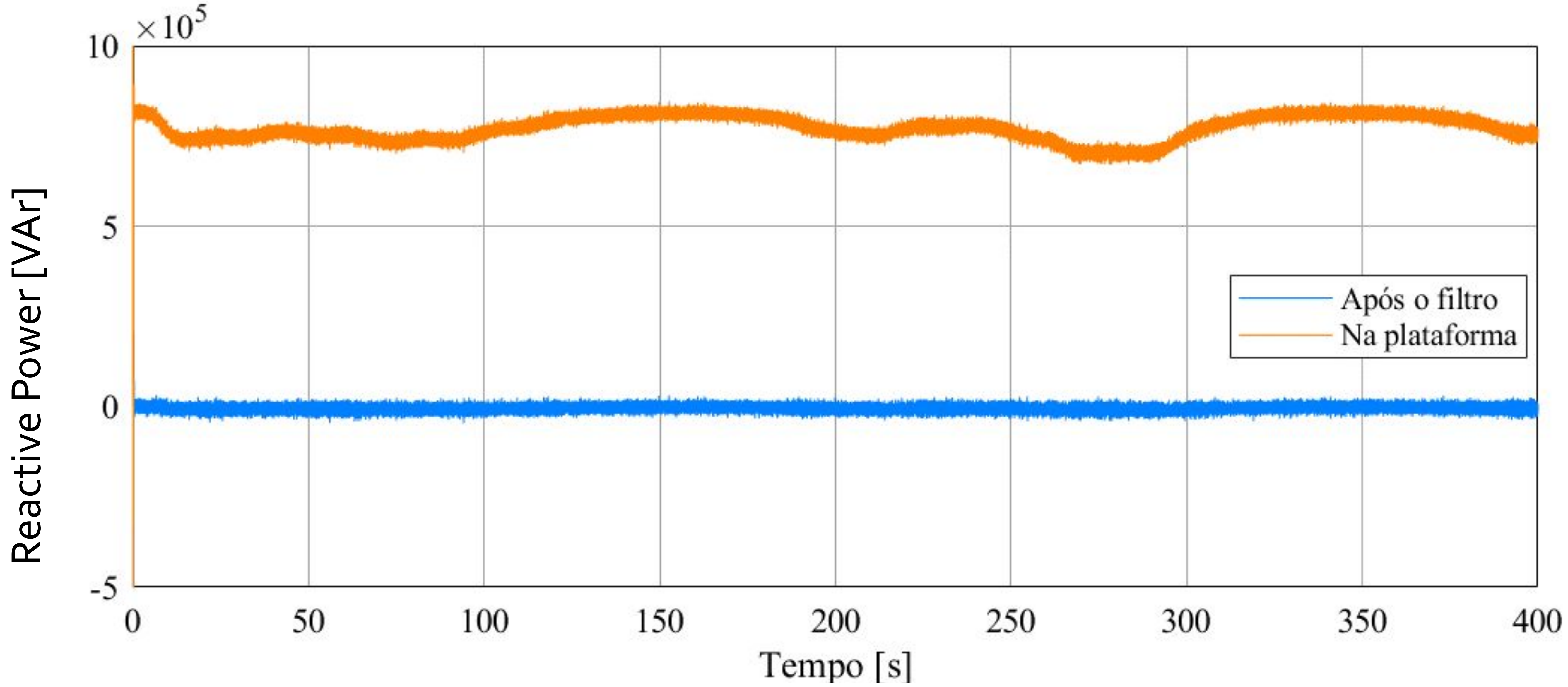
[1]LVRT: low voltage ride through

[2]HVRT: high voltage ride through

Wind Generation System Simulations - Inverter Switched Model – 10 km







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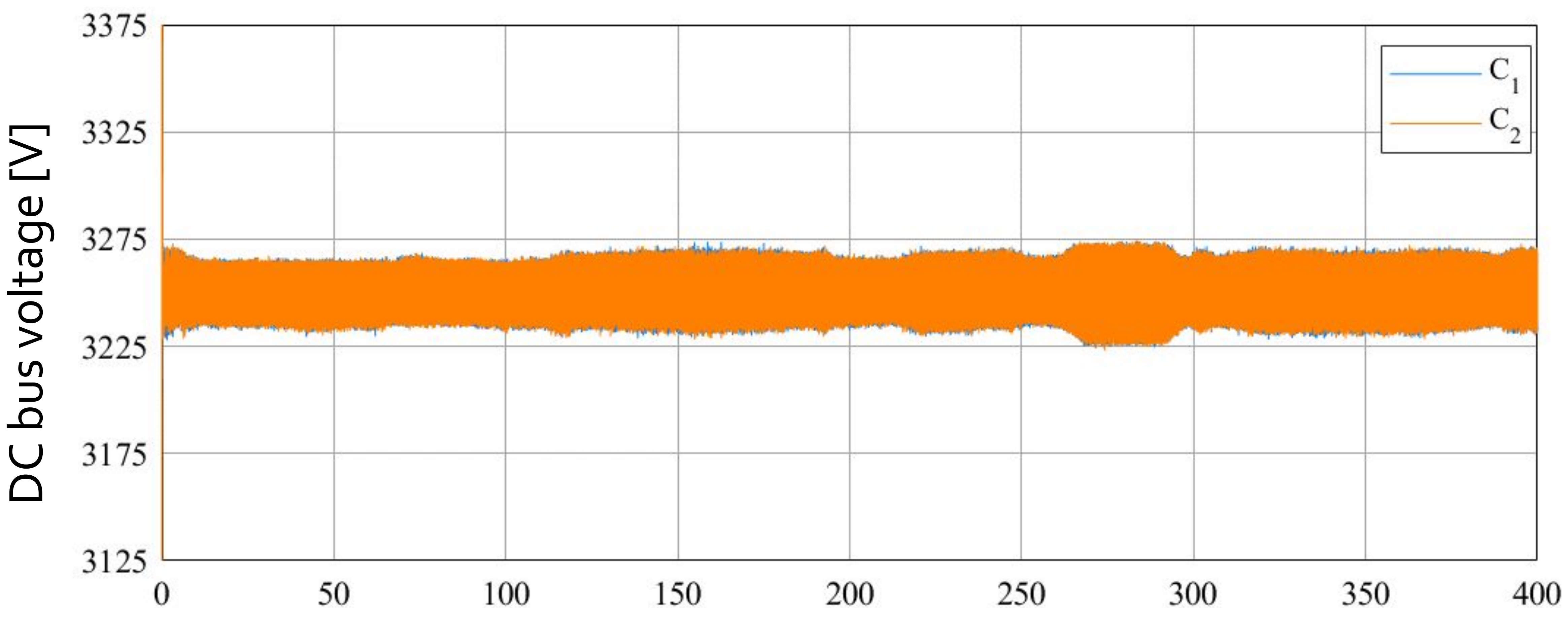
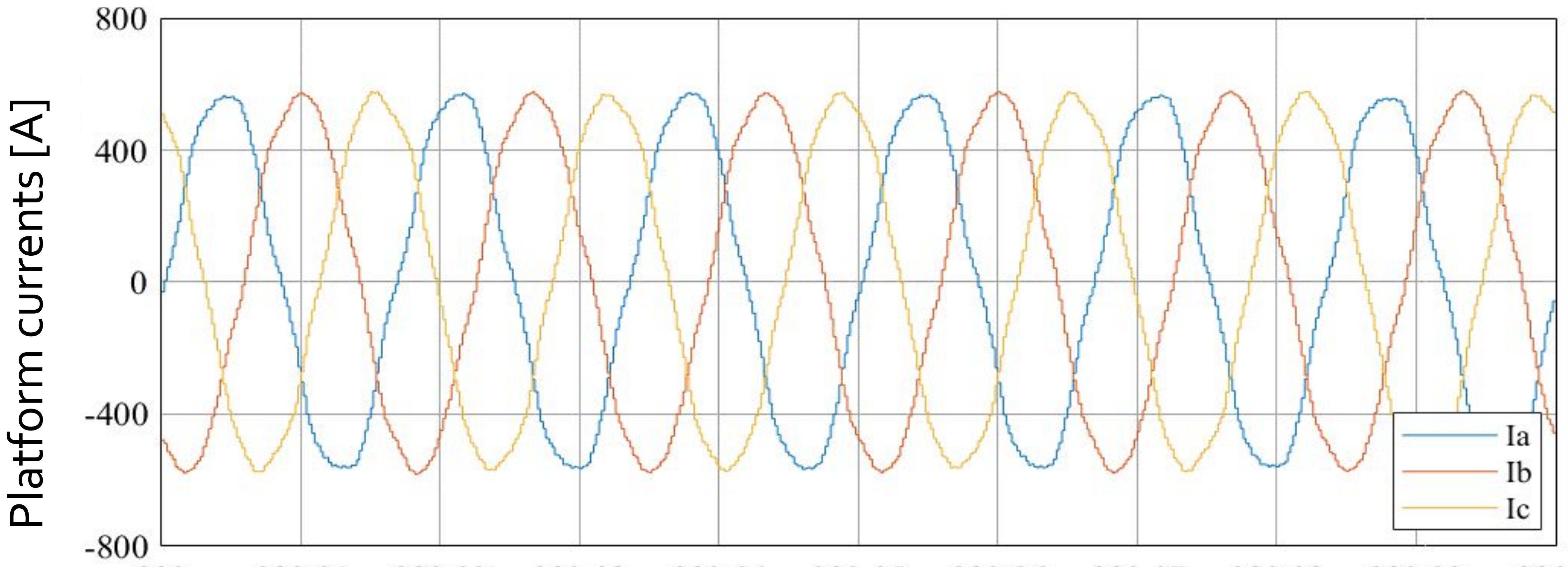
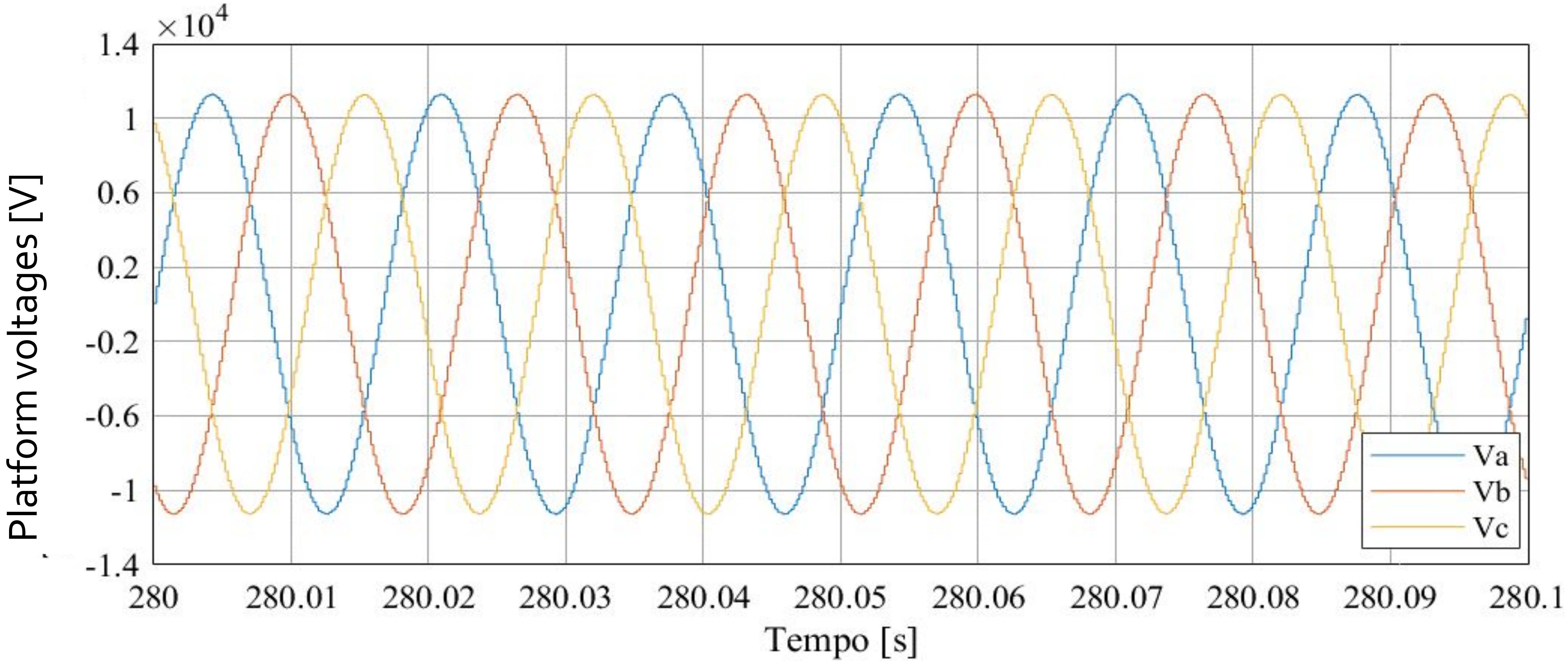
Wind Generation System Simulations - Inverter Switched Model – 10 km





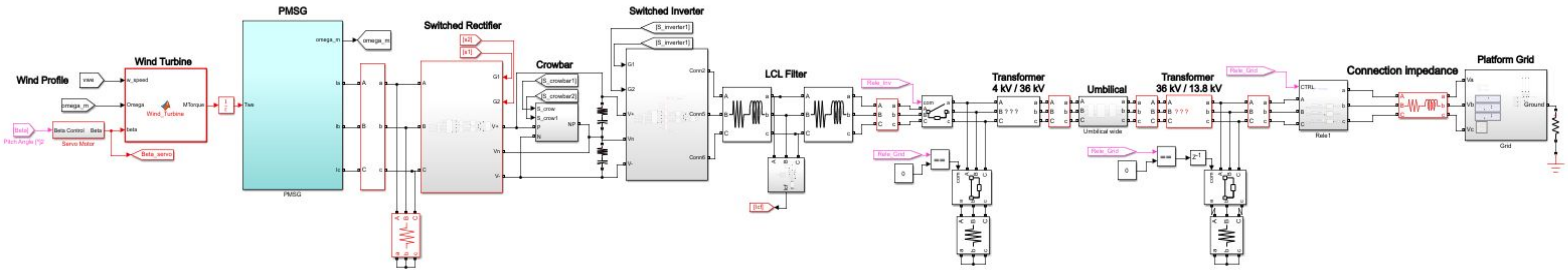


Wind Generation System Simulations

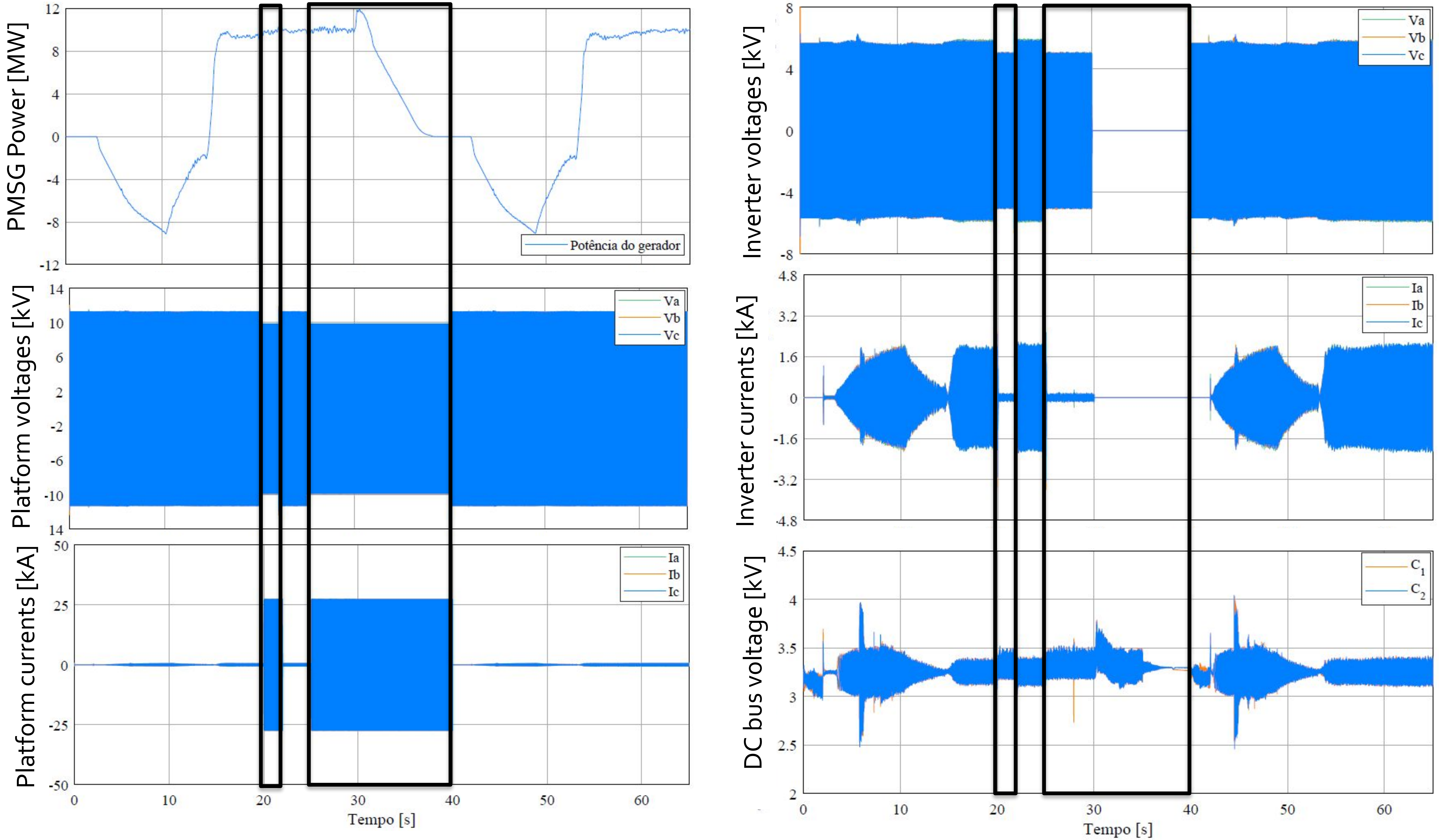
- 3° Model – Complete Switched Model:

  ✔ This is the most detailed model of the wind system. It includes all the advantages of the other models.

  ✘ However, it is a model that takes longer to simulate.

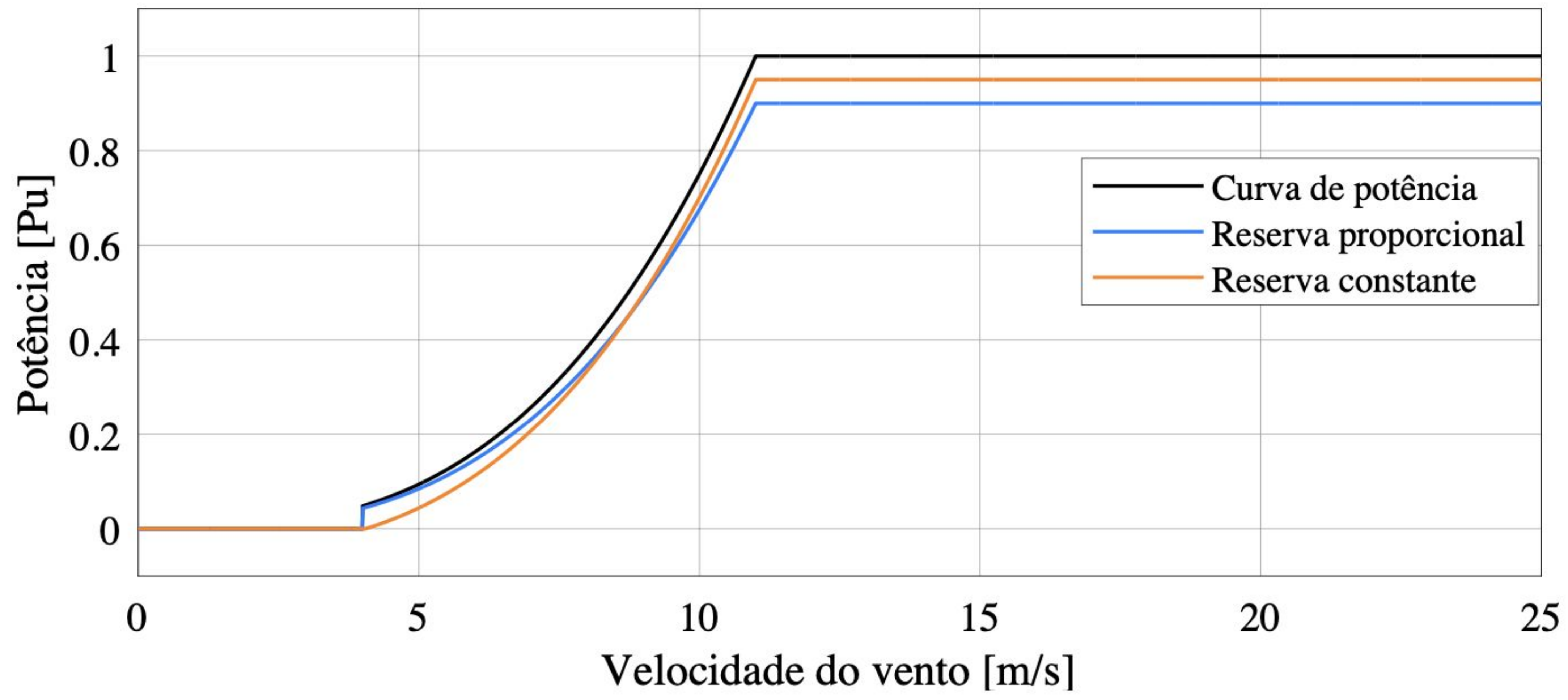


Wind Generation System Simulations - Complete Switched Model – 10 km
LVRT Test - Platform Voltages in 0,87 pu: 20 s – 22 s e 25 s – 40 s



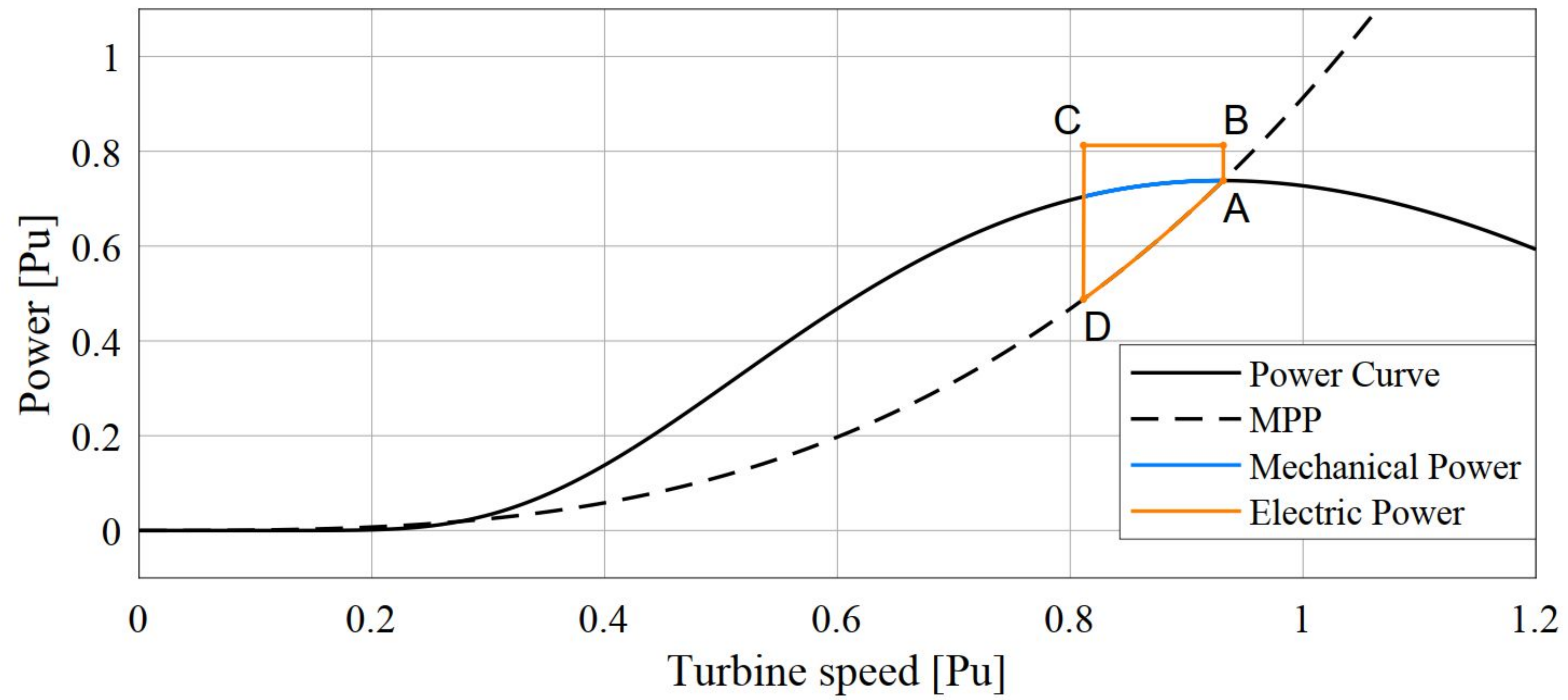
Frequency Control Support

- Droop control:
  - Deloading operation provides primary reserve.



- Inertia emulation
  - Turbine kinetic energy supports grid frequenc y deviations.

There is no storage system!



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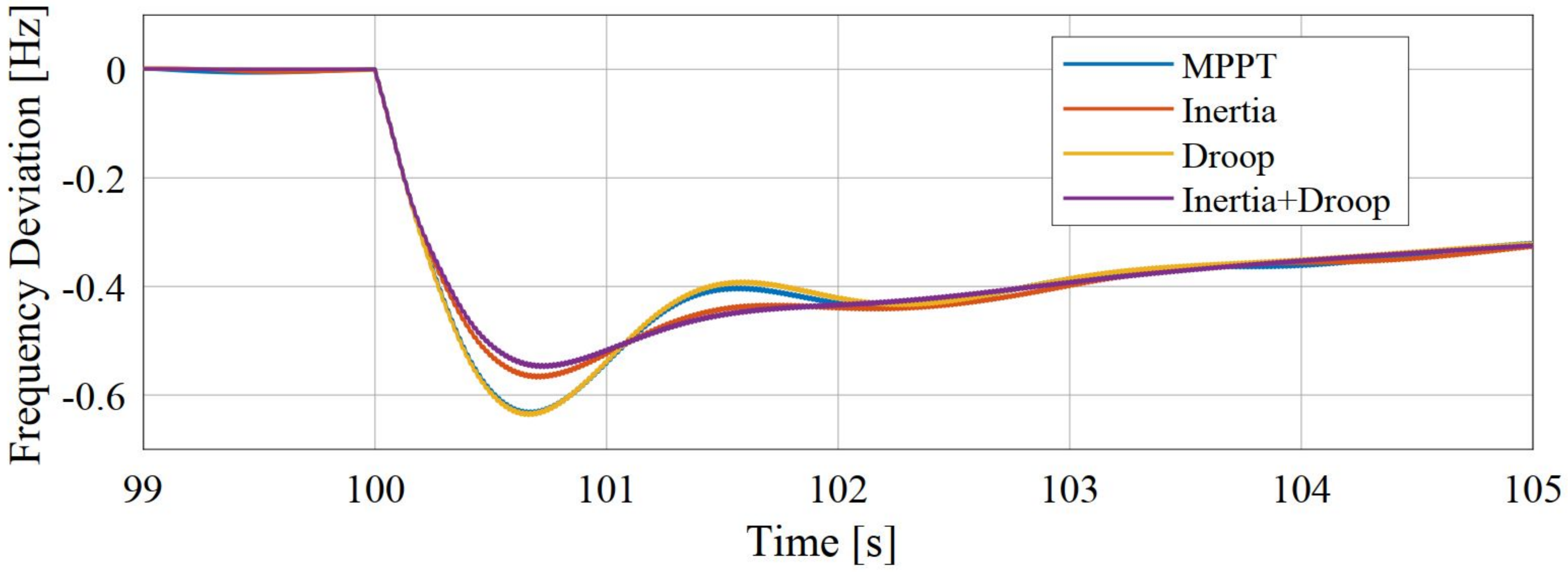
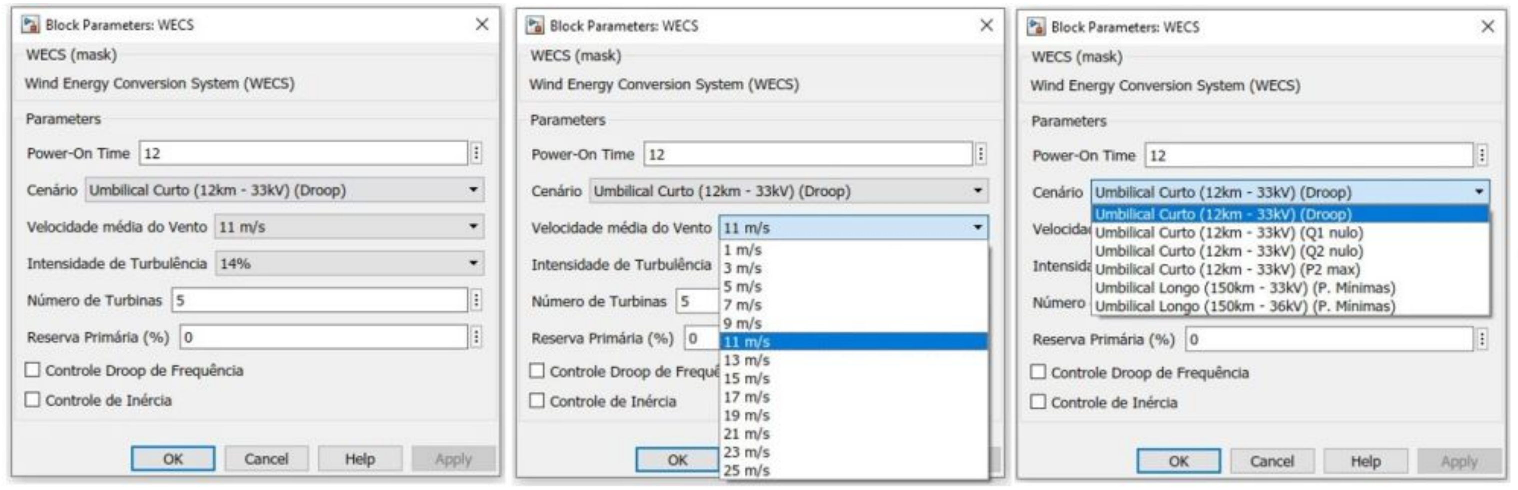
Frequency Control Support

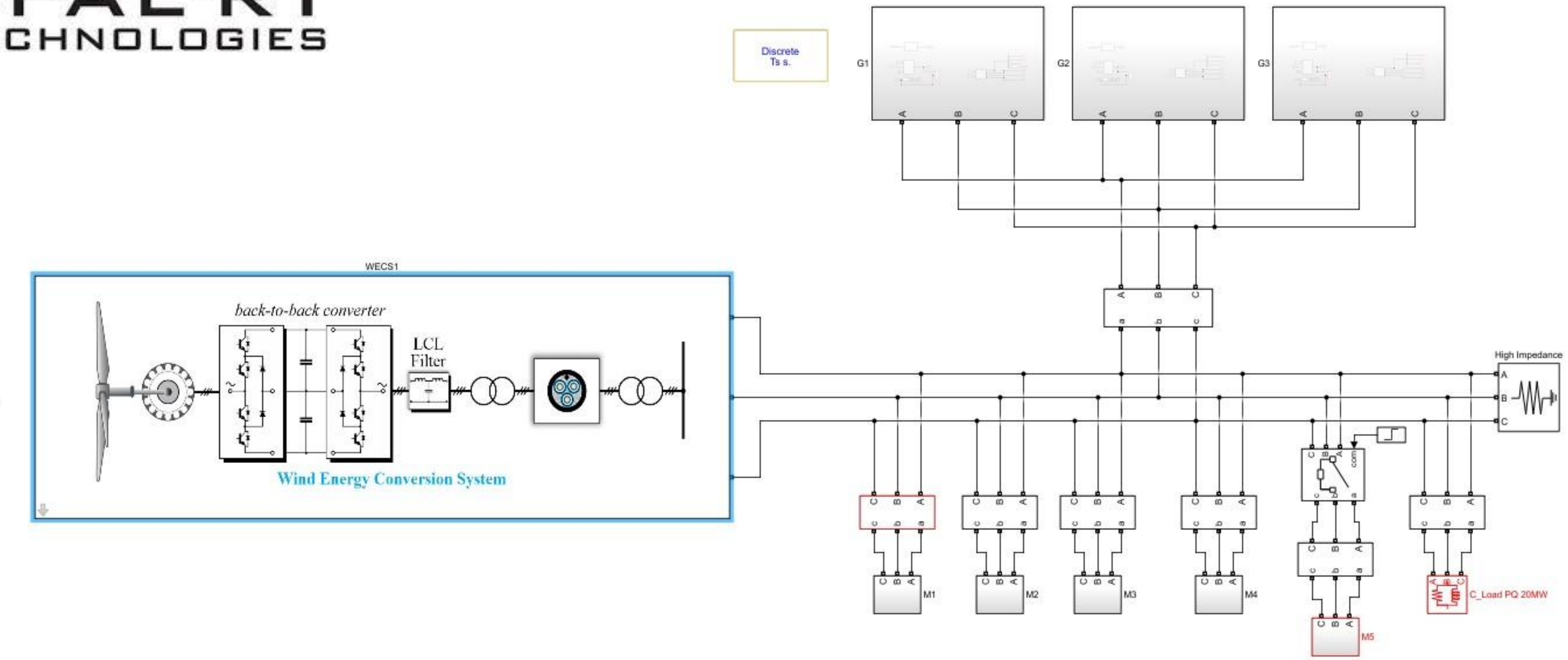
- Inertia emulation + droop deloaded control;
- Inertia control reduces the rate of change of frequency (ROCOF) right after an event;
- Droop control reduces medium-term frequency deviations.



WECS-FPSO Integration: Simplified FPSO Model

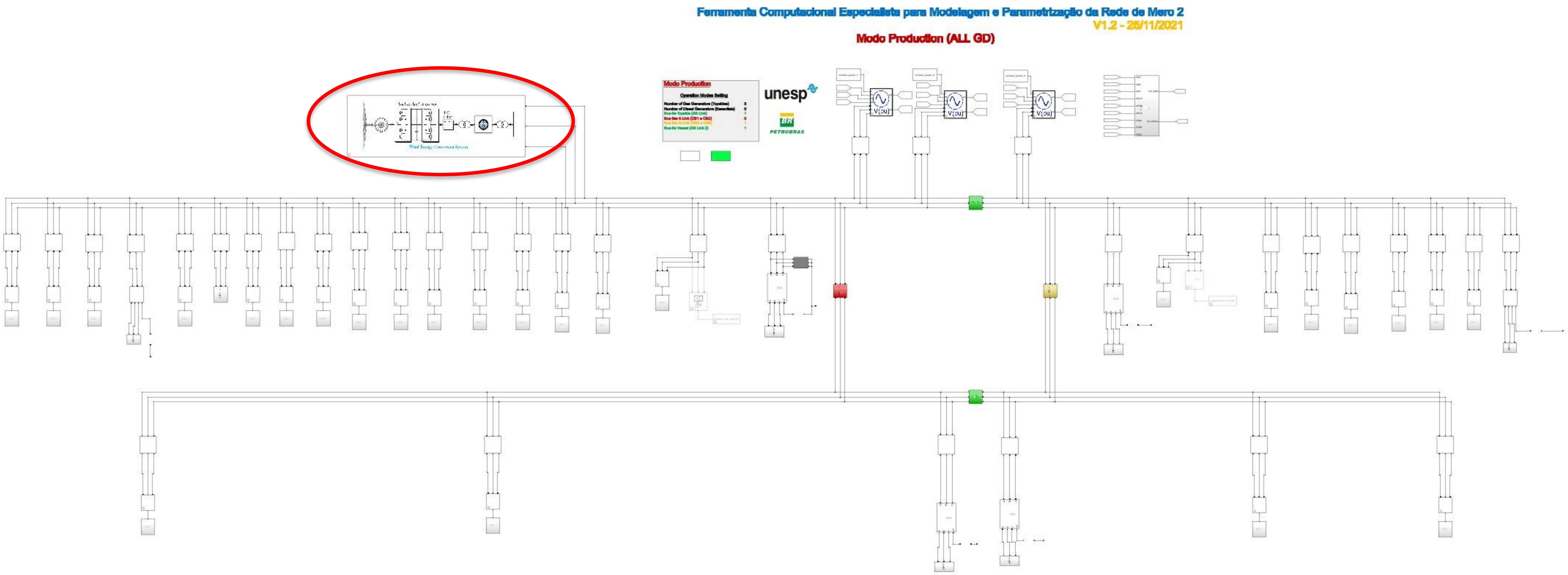
- Initially a simplified FPSO model was developed;
- It provided a first way to simulate the WECS - FPSO integration;
- Several configurations are possible (power-on time, wind intensity, wind turbulence and others) ;
- WECS initialization and steady state operation can be simulated;
- Validation Tools:





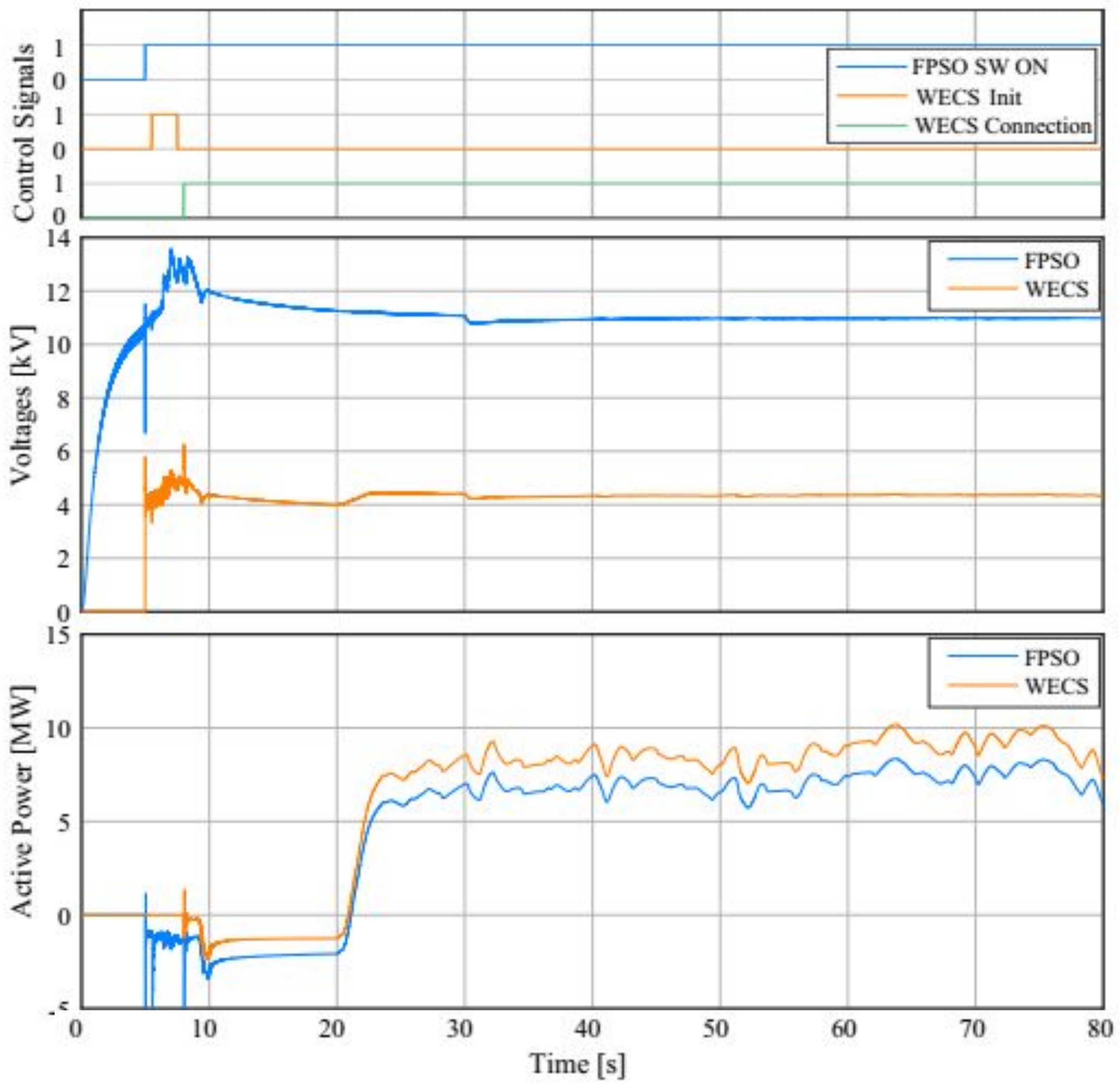
WECS-FPSO Integration: Complete FPSO Model

- The complete FPSO model produced by UNESP was also employed to complete the system analysis;
- Simulation results are in agreement with the FPSO load data.

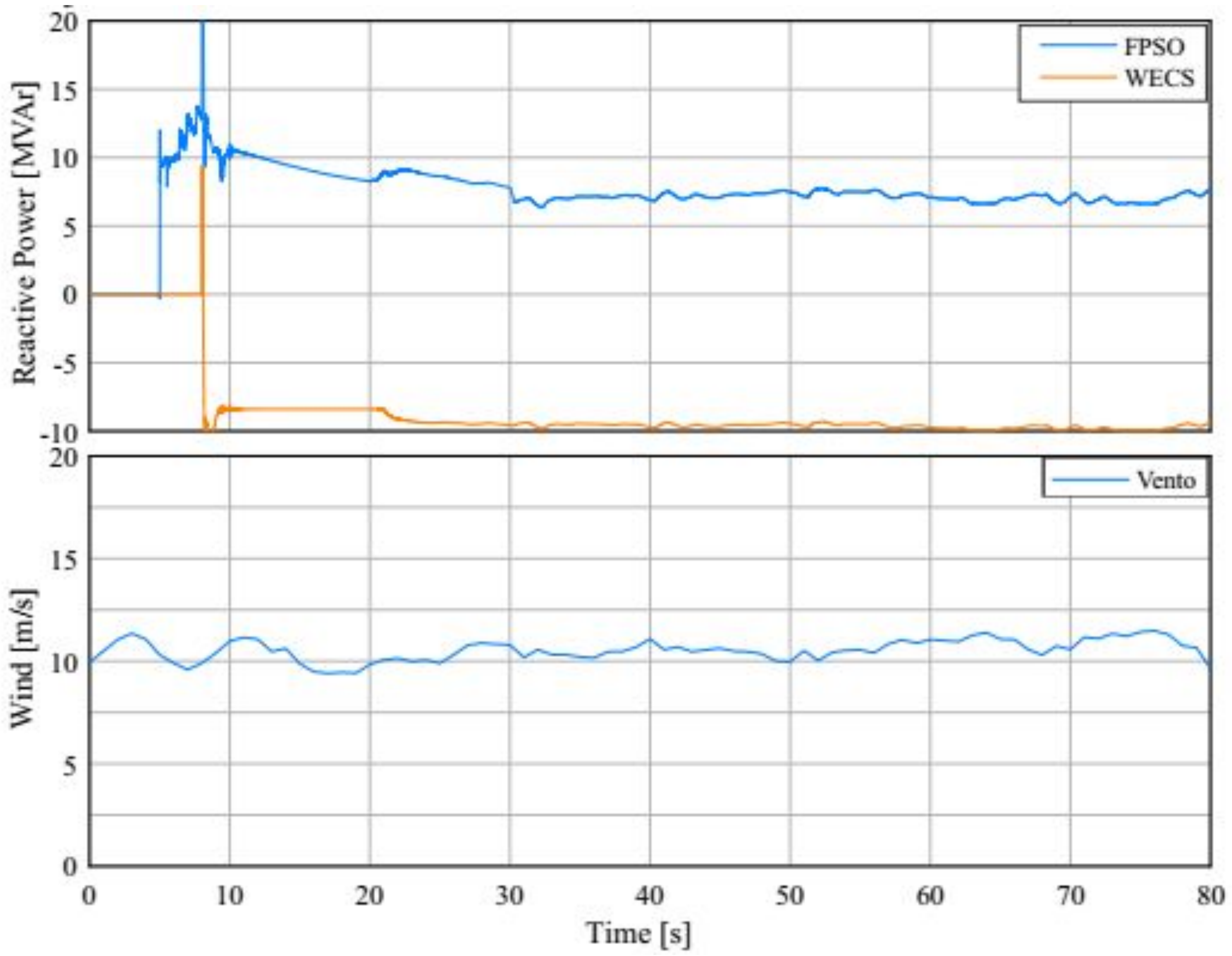


WECS-FPSO Integration: Operation Example

- WECS-FPSO distance 150km;
- Wind (mean value) 11m/s;
- Transmission Line Voltage 36kV;

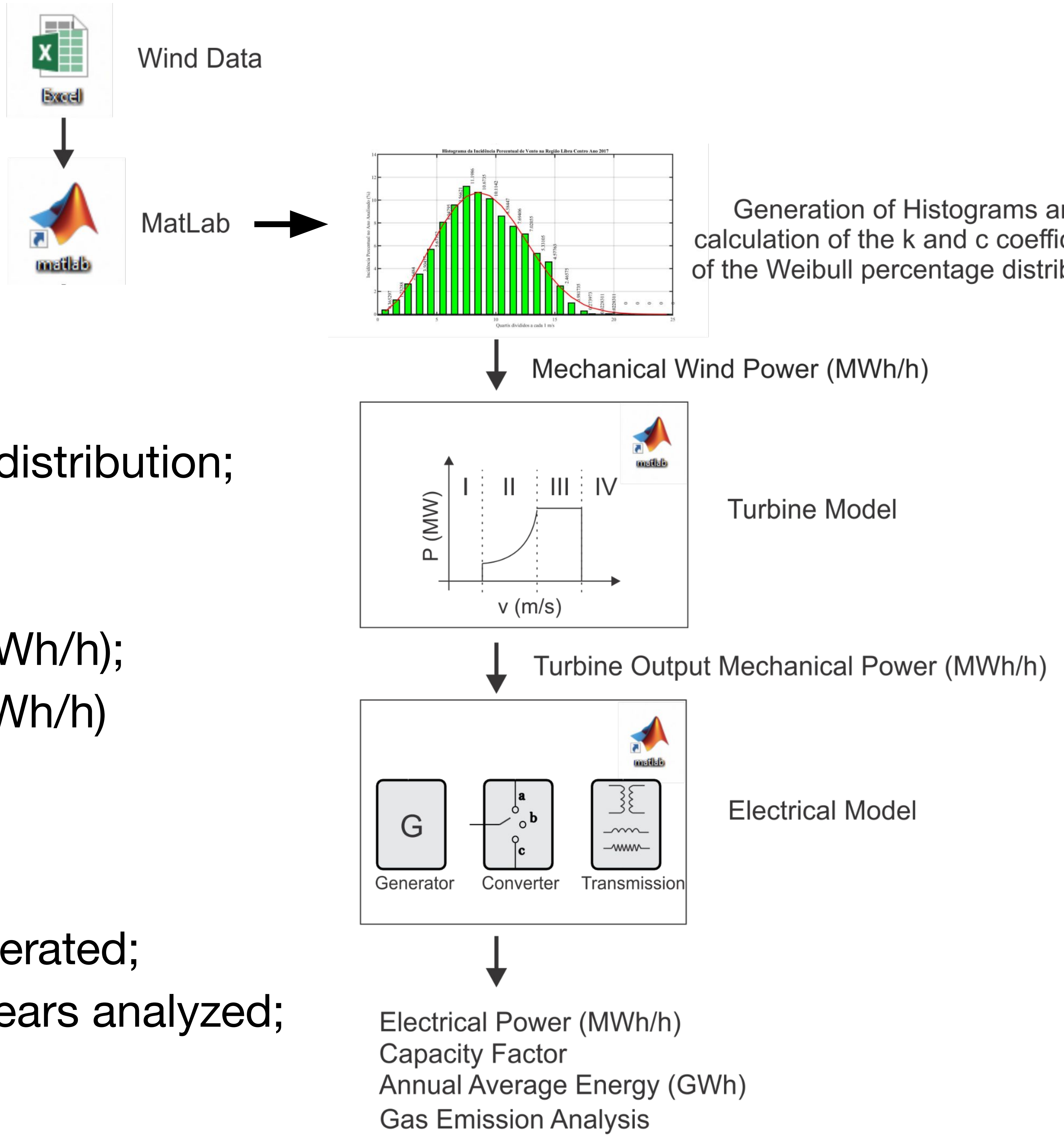


- Operation Sequence:
  - ❑ FPSO switch on (Umbilical energization);
  - ❑ Inverter initialization (dc-link charge);
  - ❑ WECS-FPSO connection;
  - ❑ Turbine acceleration;
  - ❑ Steady state (Power Generation)

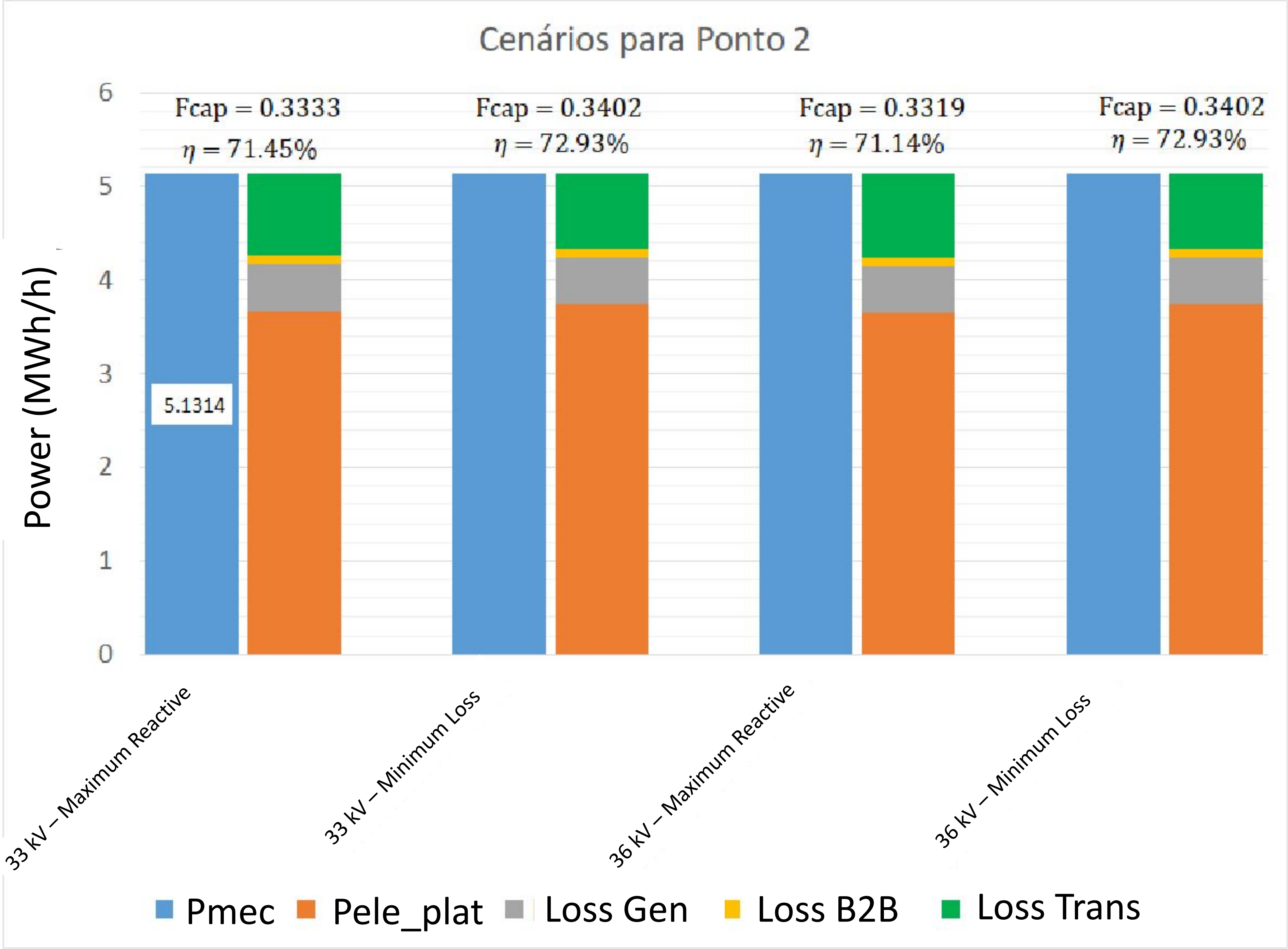


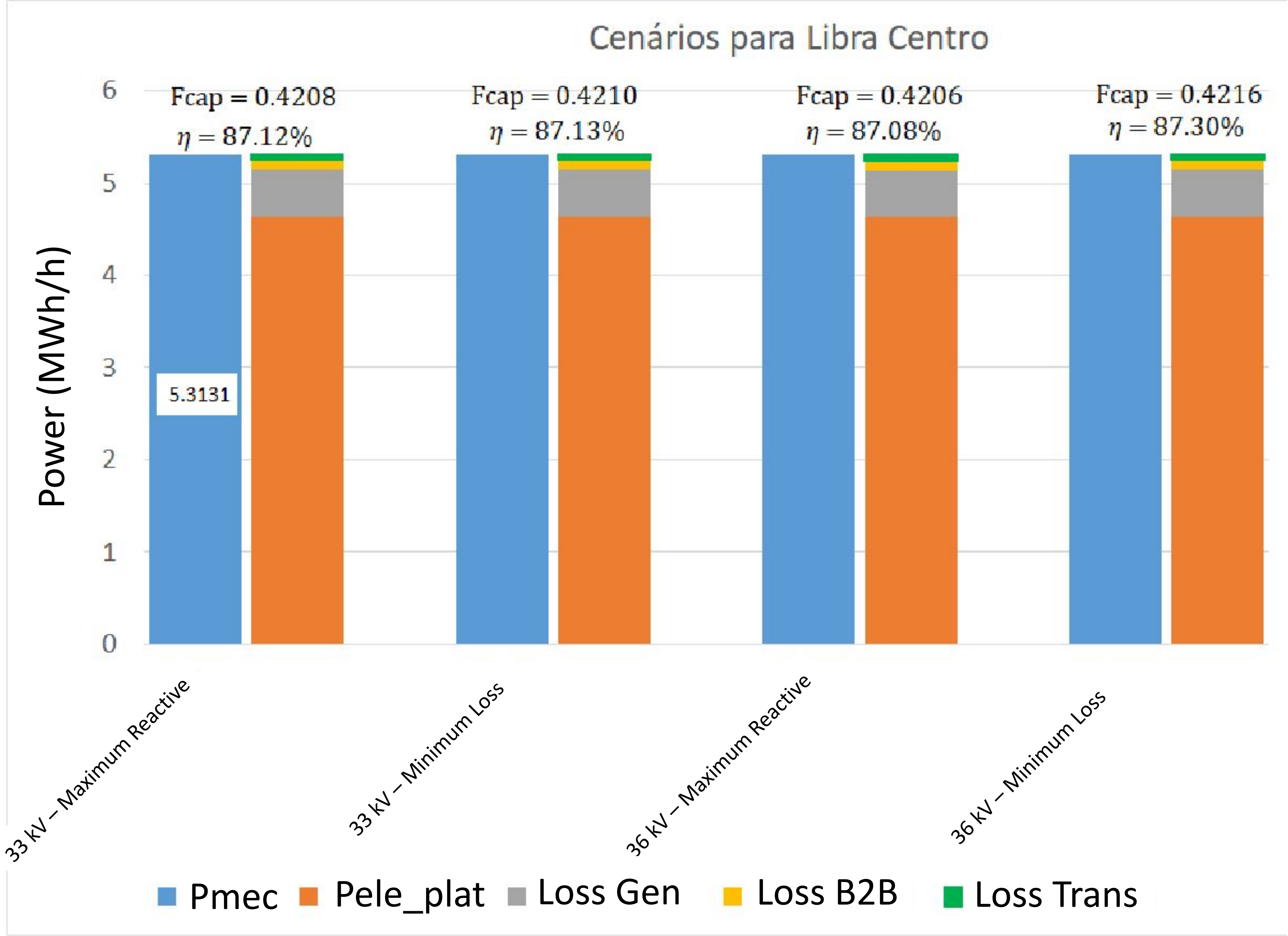
Energy Analysis Tool

- Implementation for data processing via MatLab
- Features:
  - Obtaining the Annual Maximum Speed;
  - Obtaining the Minimum Annual Speed;
  - Obtaining the Annual Average Speed;
  - Histogram Plot for 1 m/s quartiles;
  - Obtaining the parameters of the Weibull percentage distribution;
  - Weibull Probability Curve Plot;
  - Inclusion of Turbine parameters;
  - Calculation of Annual Average Mechanical Power (MWh/h);
  - Calculation of the Annual Average Electric Power (MWh/h) considering
  - the efficiency of the system;
  - Capacity Factor Calculation;
  - Calculation of the Annual Average Energy (GWh) generated;
  - Calculation of the Total Energy generated in the 20 years analyzed;
  - Calculation of Gas Emissions.

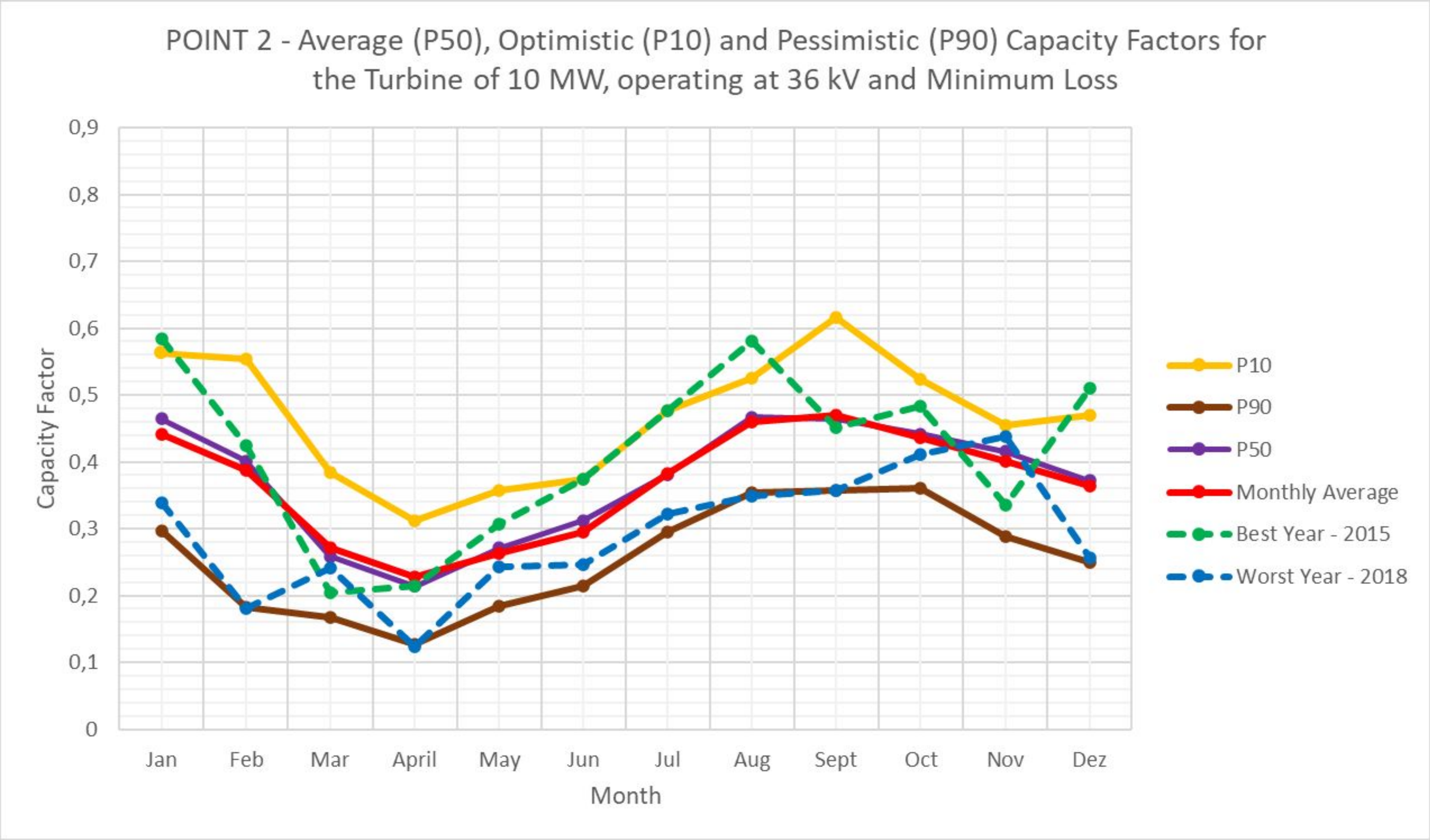


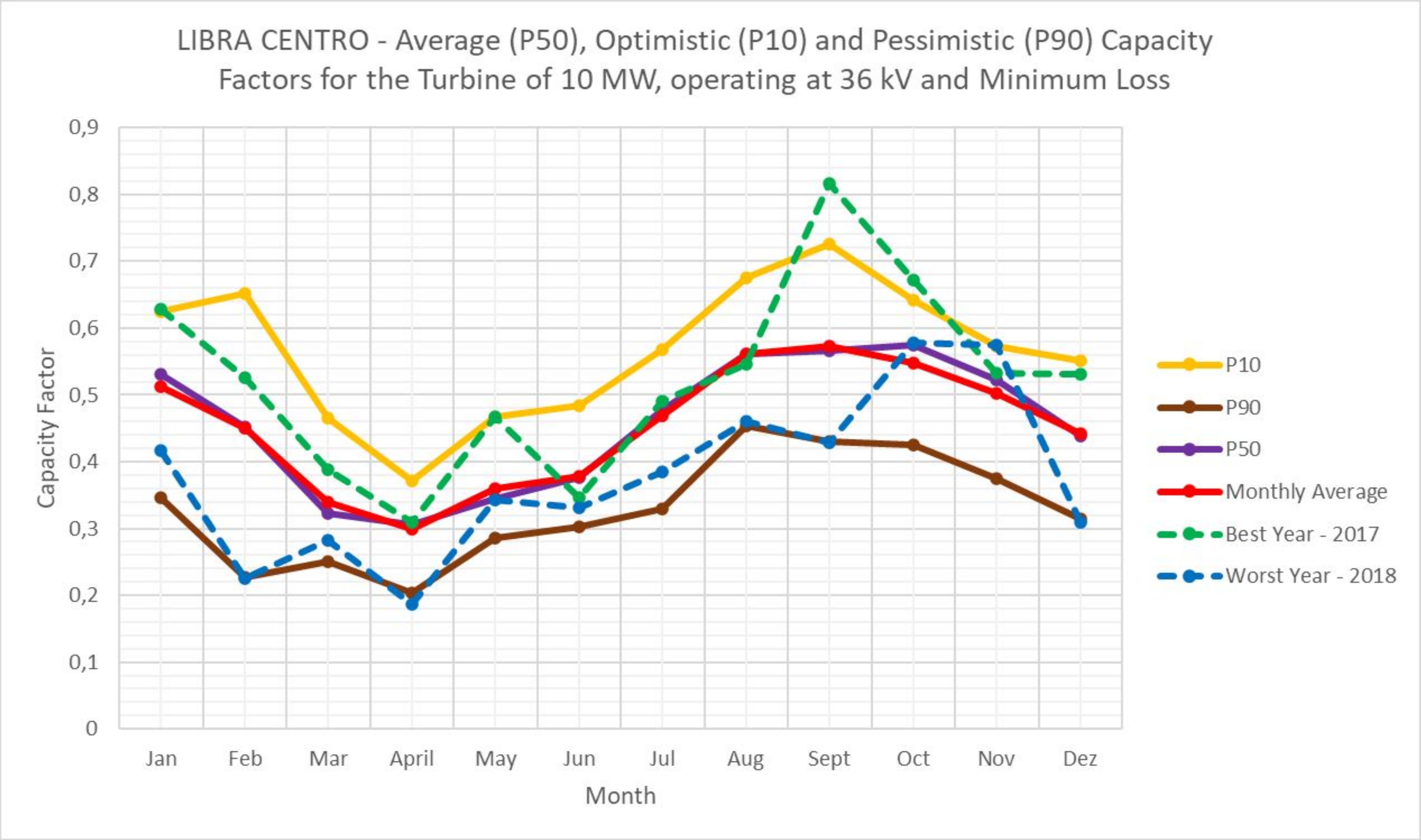
Energy Analysis Tool – Power loss distribution (20 years)



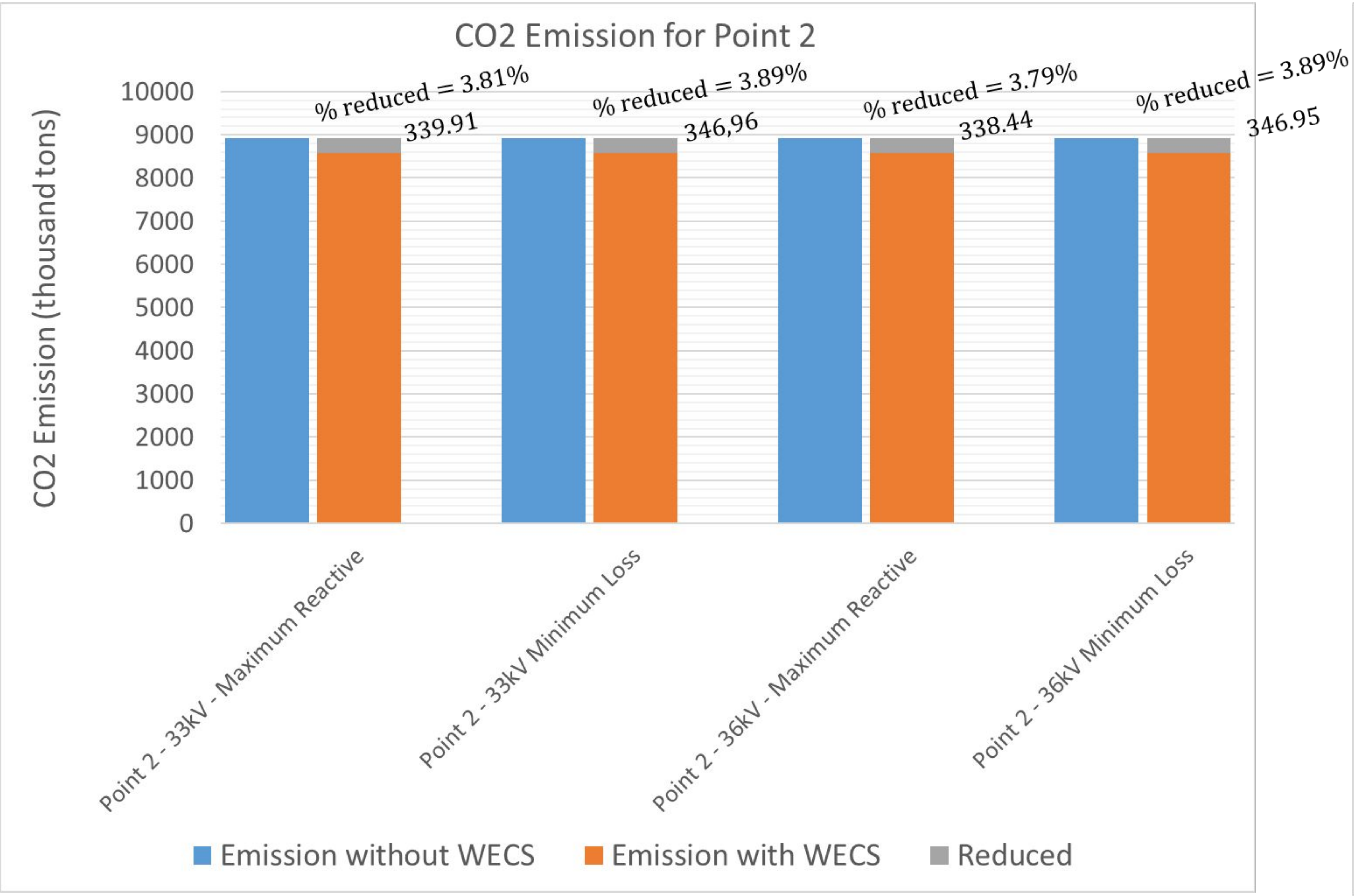


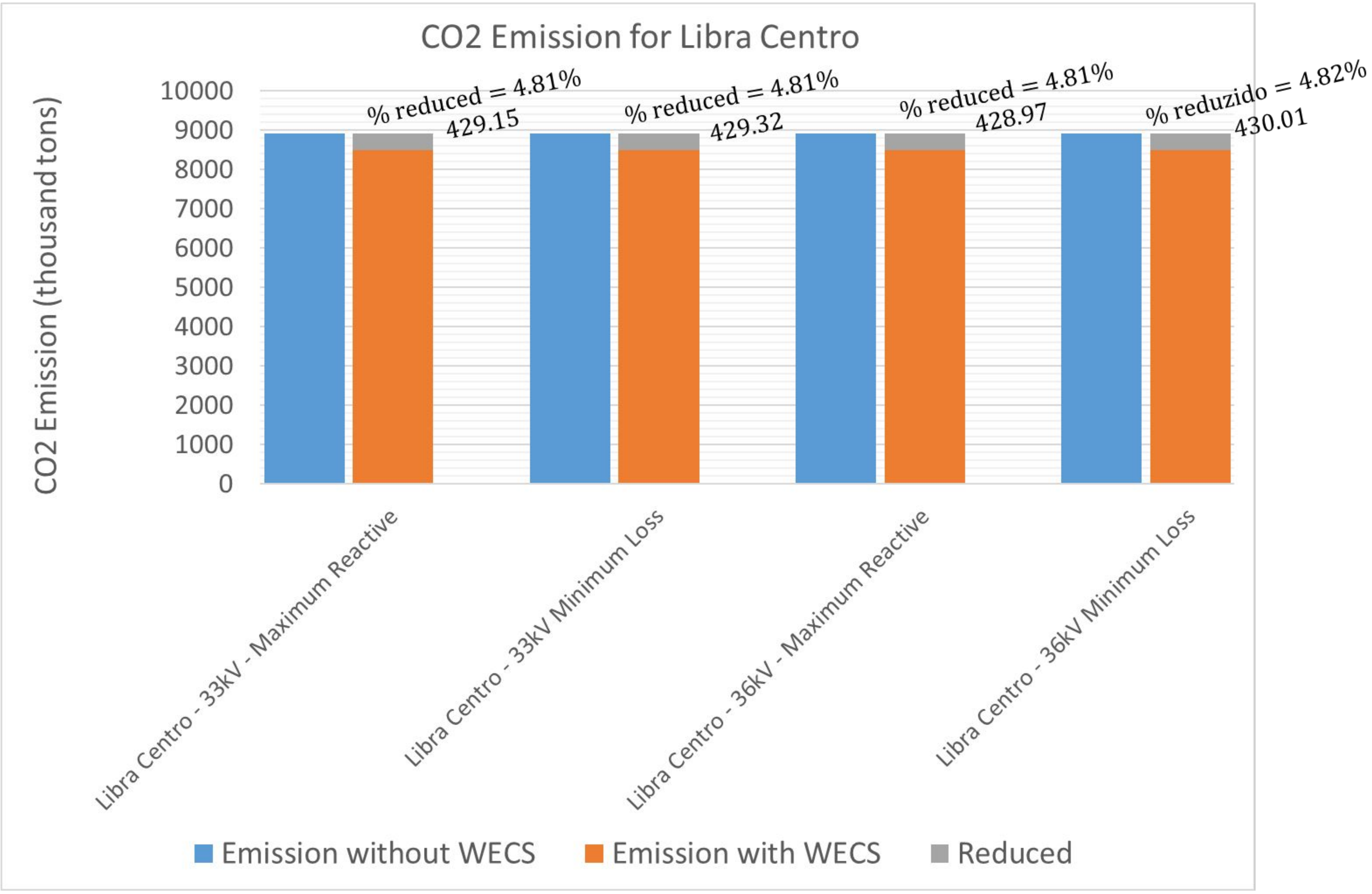
Energy Analysis Tool – Capacity Factors (P10, P90, and P50)





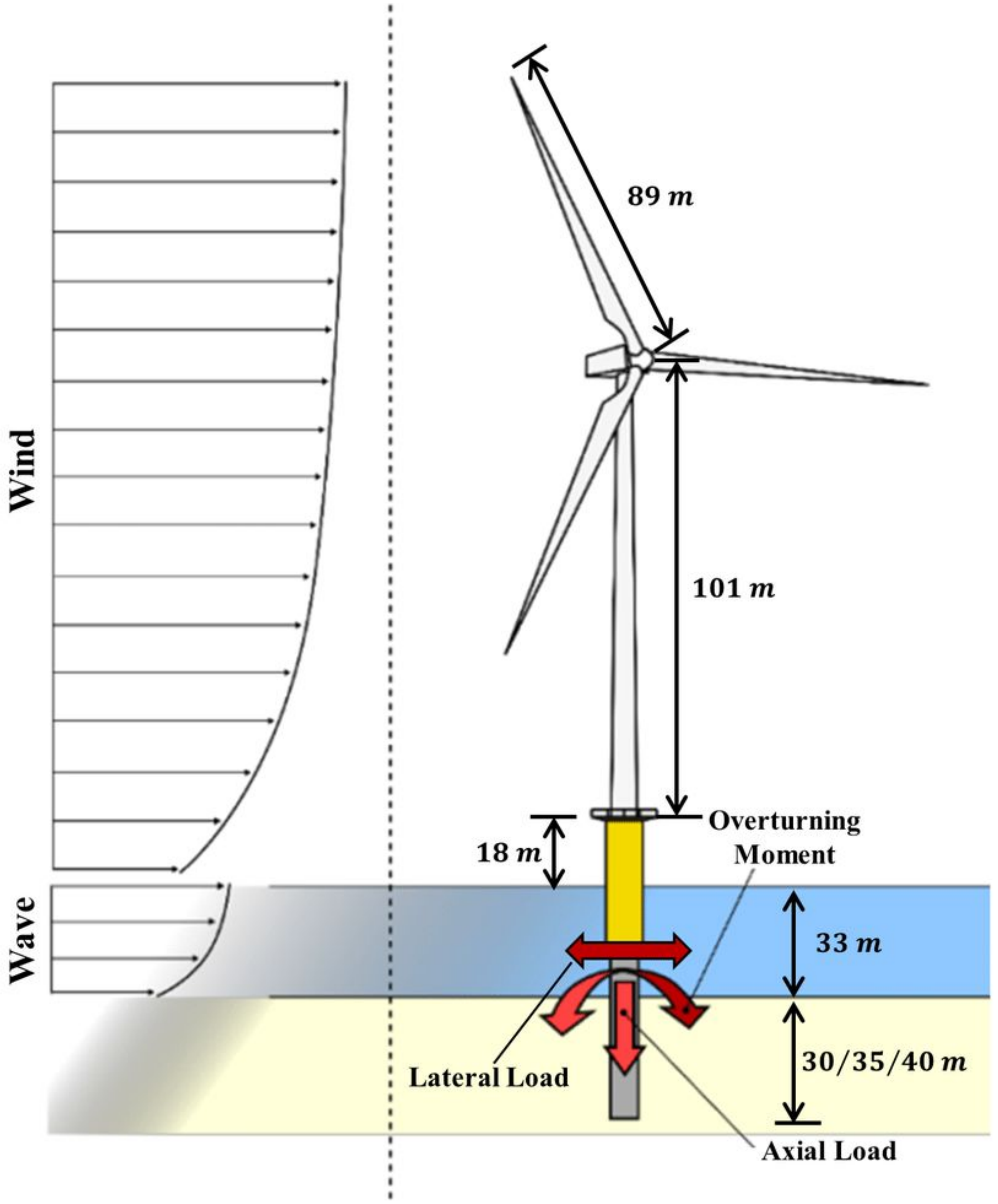
Energy Analysis Tool – CO2 equivalent emission (20 years)

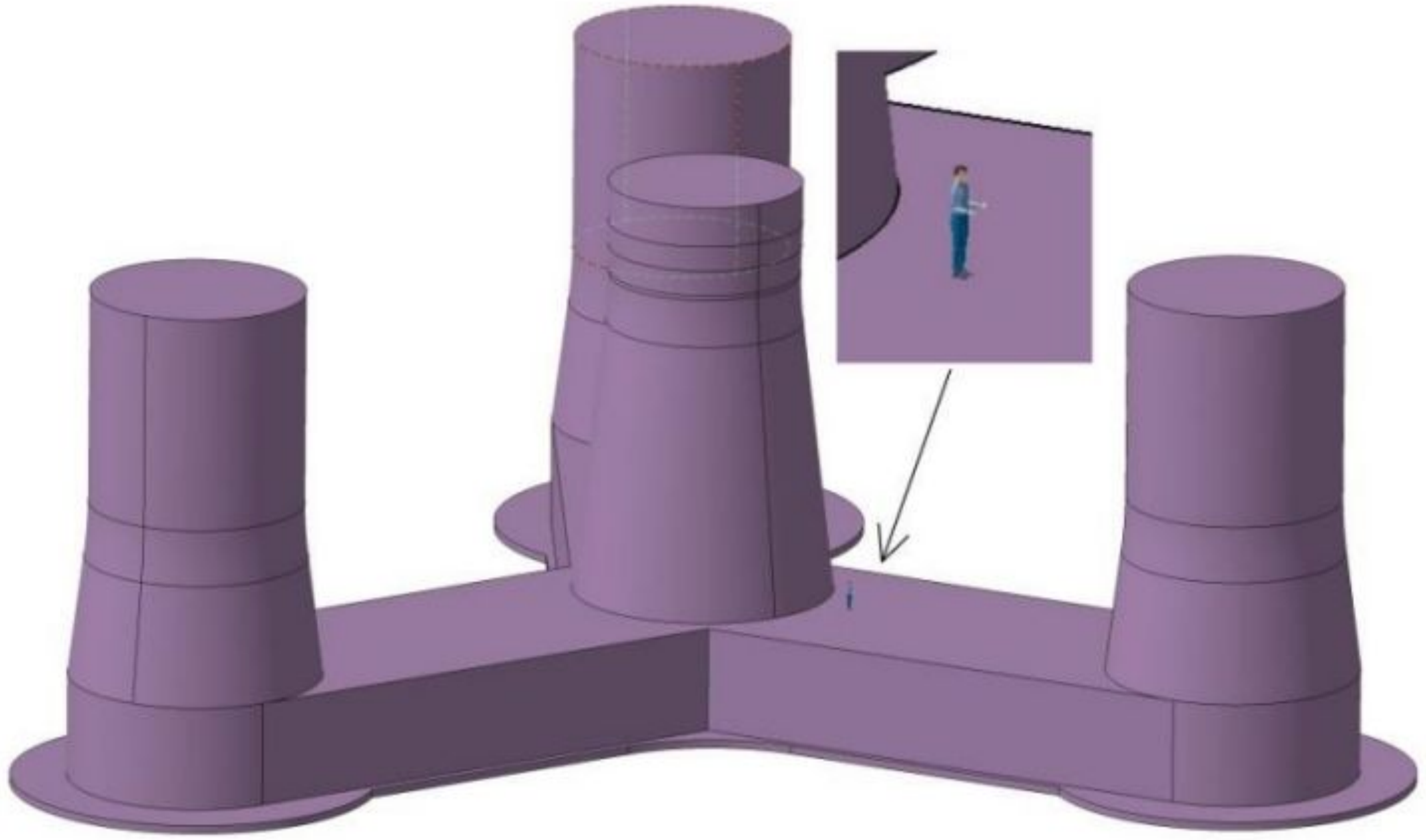




Offshore Wind Turbine Structural Analysis

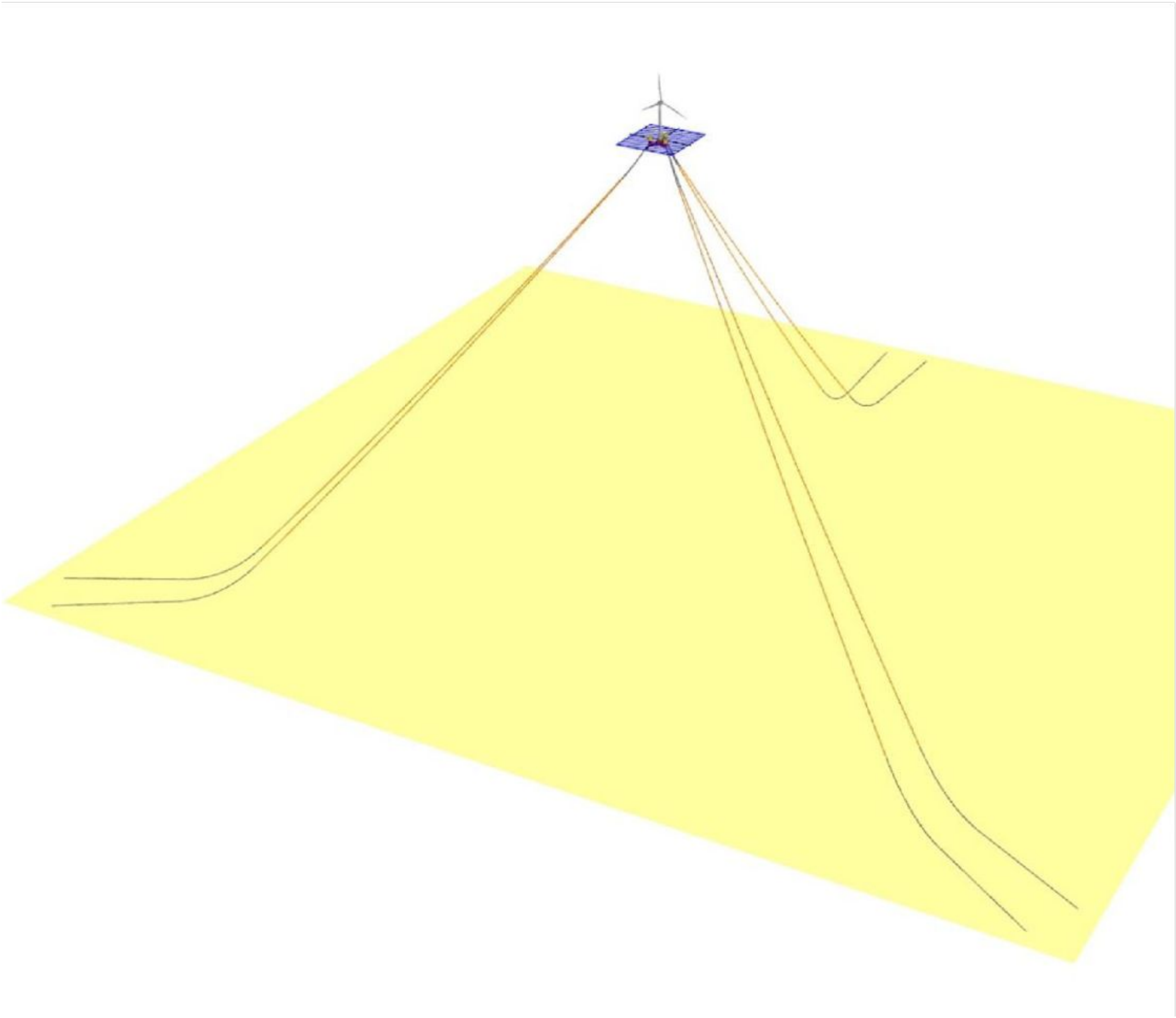
- Objectives:
  - ❑ Describe the main mechanical load types considered in WT design on offshore environment;
  - ❑ Investigate the structural features of the offshore WT platforms and identify the main projects of offshore structures;
  - ❑ Perform preliminary simulations of Floating Offshore Wind Turbines (FOWT) for Deep Waters.

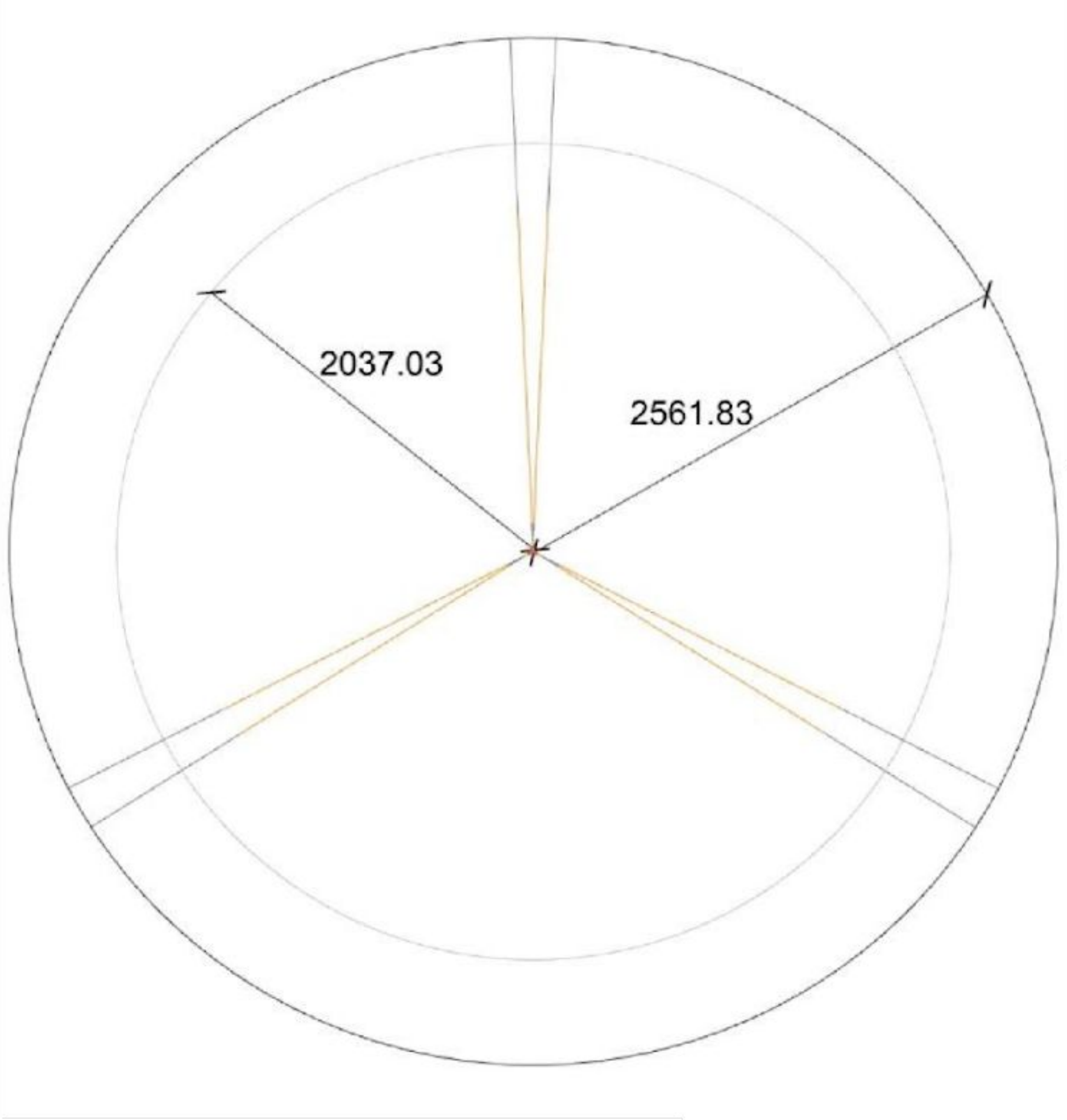


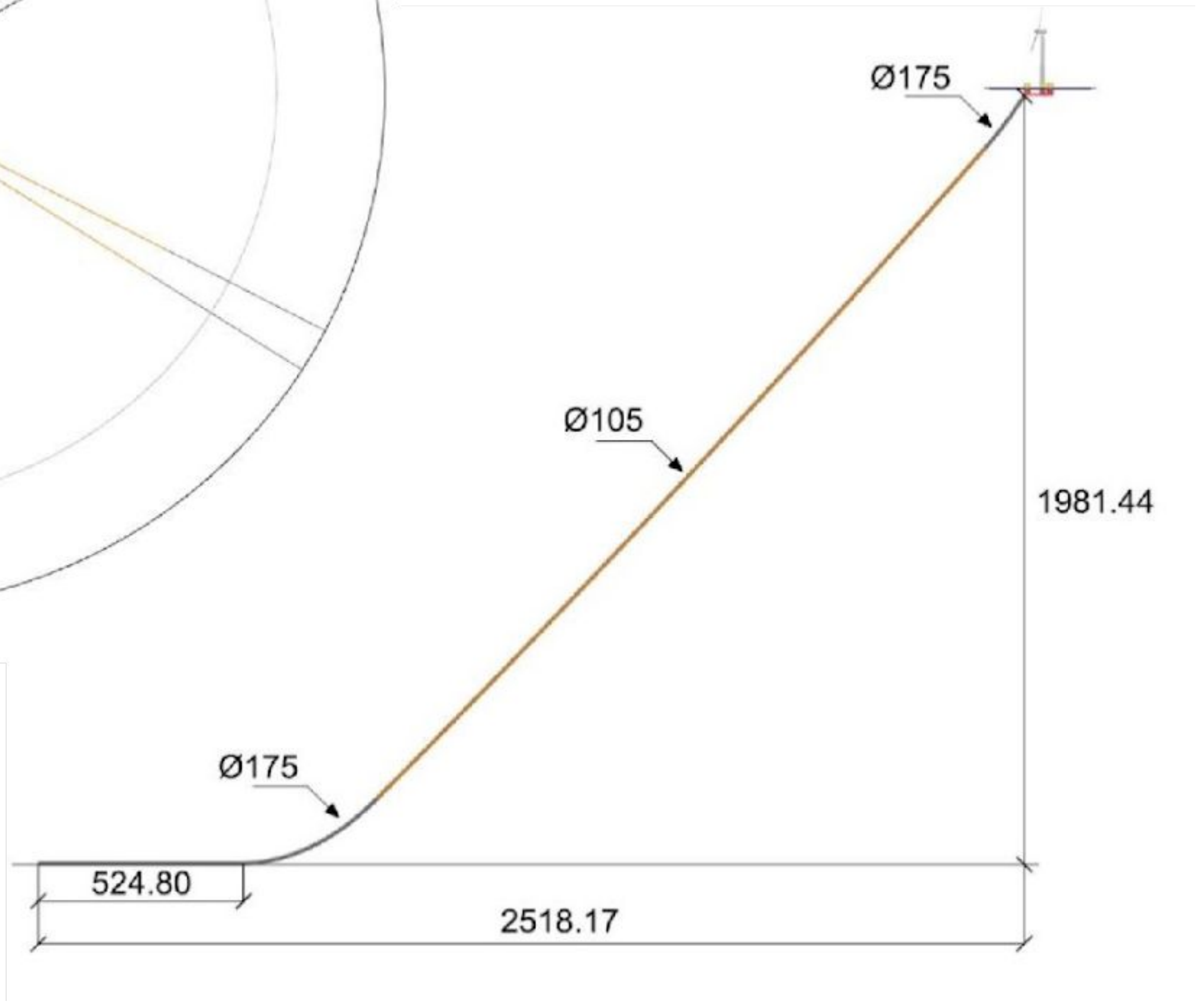


Offshore Wind Turbine Structural Analysis

- Mooring Lines design provided by Prof Alexandre N. Simos and team (POLI-USP).

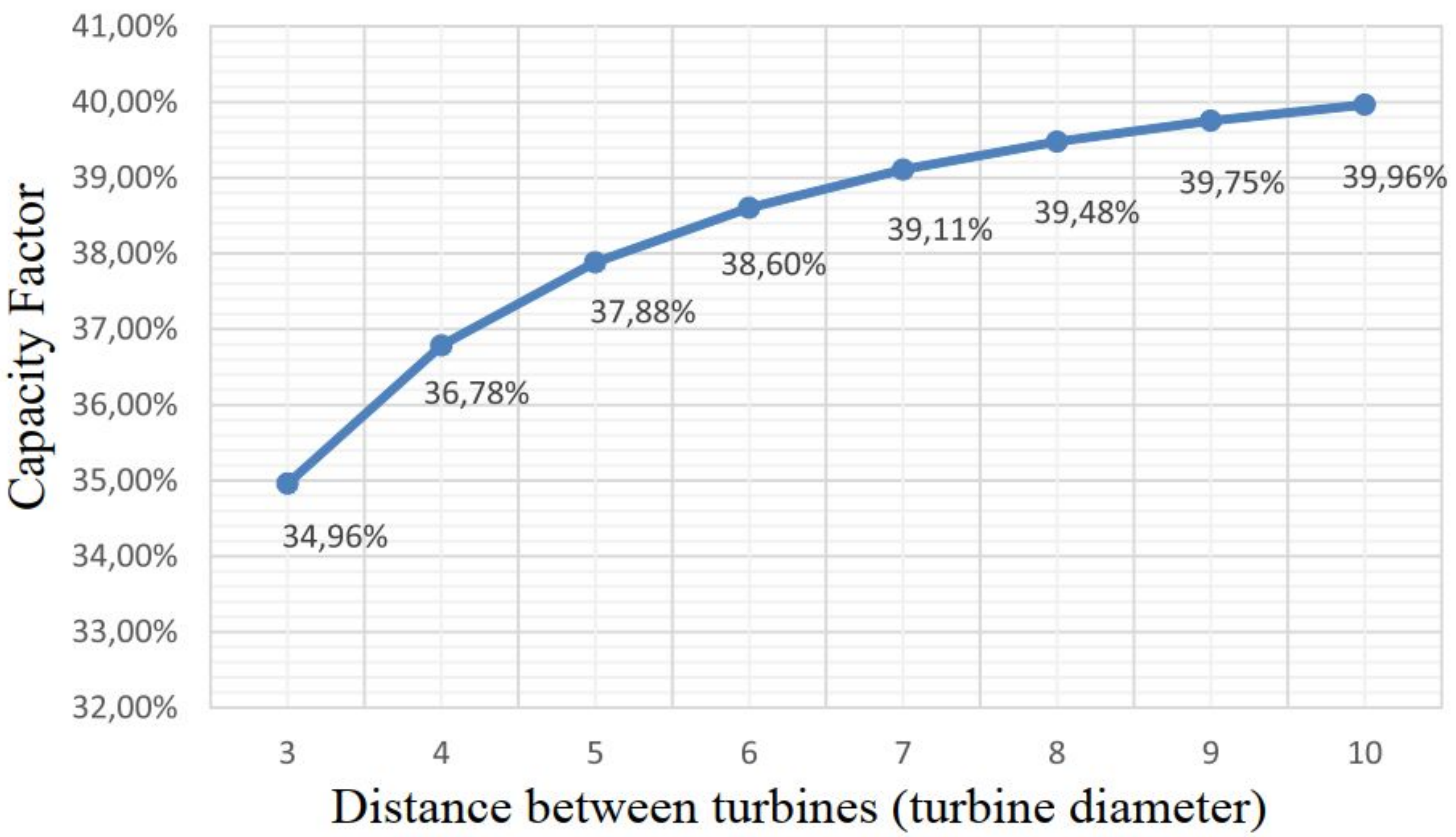


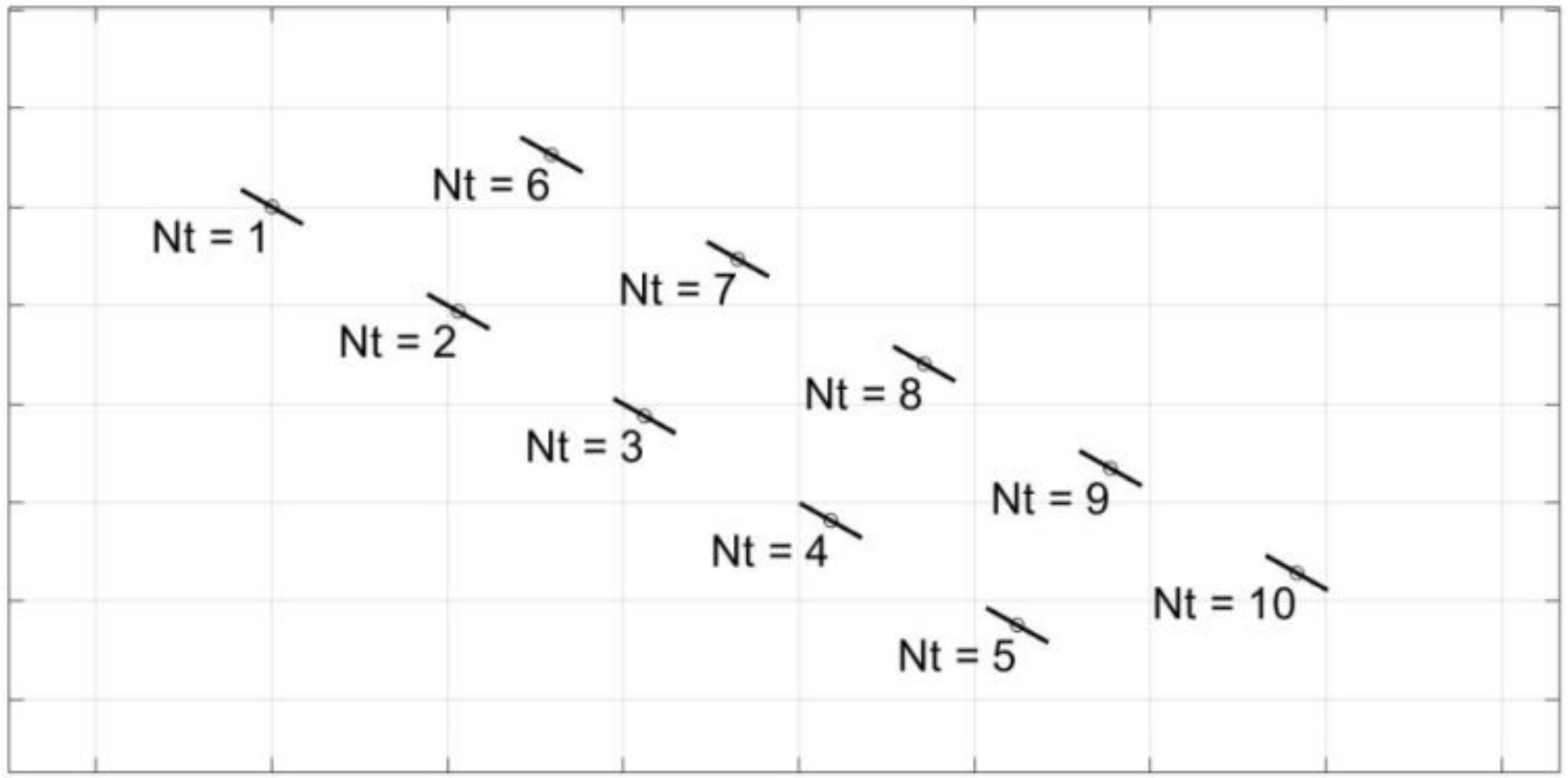




Wind Farm

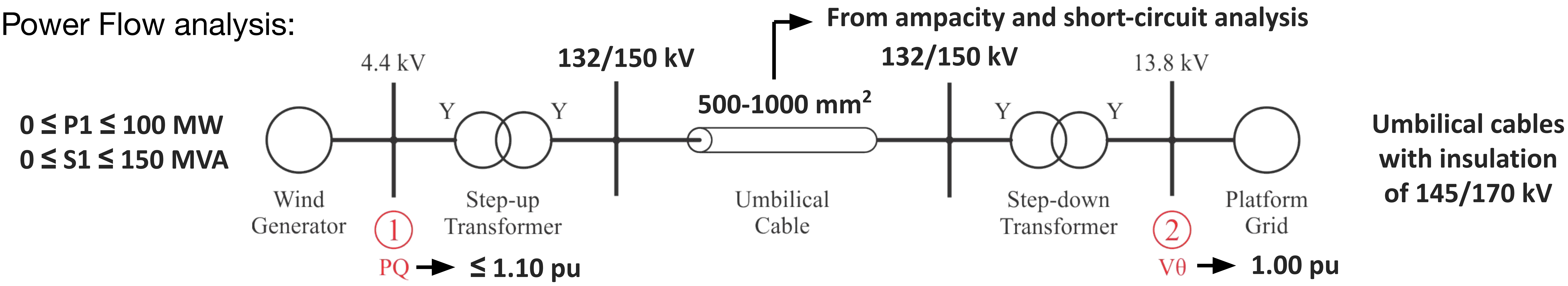
- Wake Effect
  - Lower wind at downstream turbines
  - Analysis: Cable length vs Capacity factor
  - Analysis based on 20-year wind profile





Wind Farm – Transmission System

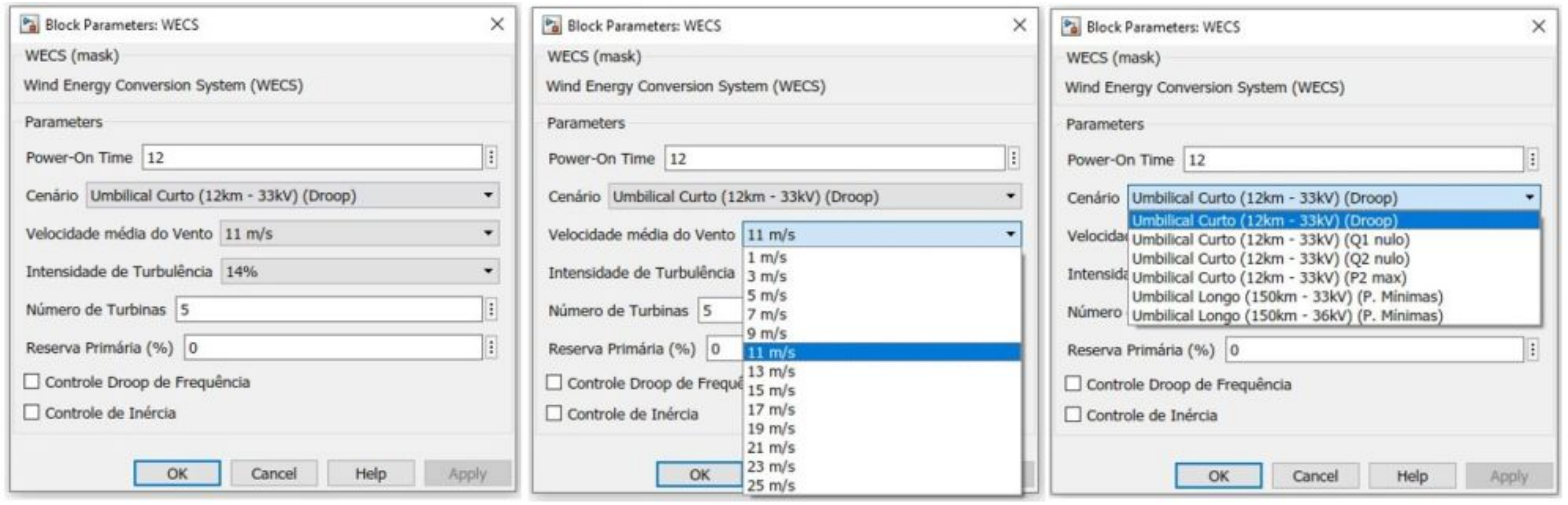
- Power Flow analysis:

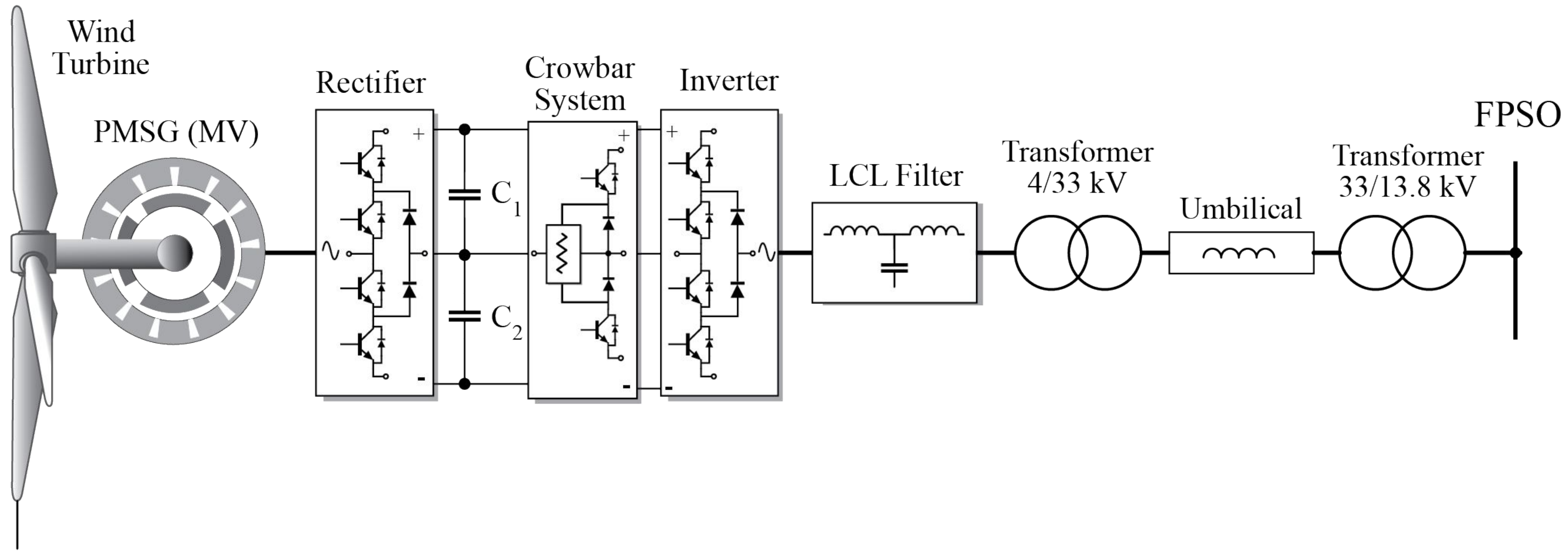


- The power loss is below 5% in average, but the umbilical generates a lot of reactive power over long distances.
- The usage of umbilical cables in parallel further exacerbates this problem due to the increase in capacitance.
- Shunt reactors can be used to absorb the capacitive reactive power delivered to the FPSO, but these devices requires too much space over there.
- Transmission with low frequency (20 Hz) or HVDC allows to reduce the transmission losses and the capacitive reactive power delivered to the platform. In this case, the reactive generated by the umbilical can be fully absorbed by the B2B converter, without the need for shunt reactors.

Products

- Electrical model (three different models);
- Thermal model;
- Energy analysis tool (including CO2eq reduction estimation);
- Preliminary structural study for a 2000-m floating system;
- Results of a 10 MW Offshore WECS connected to an FPSO through an umbilical of 10 km and 150 km.

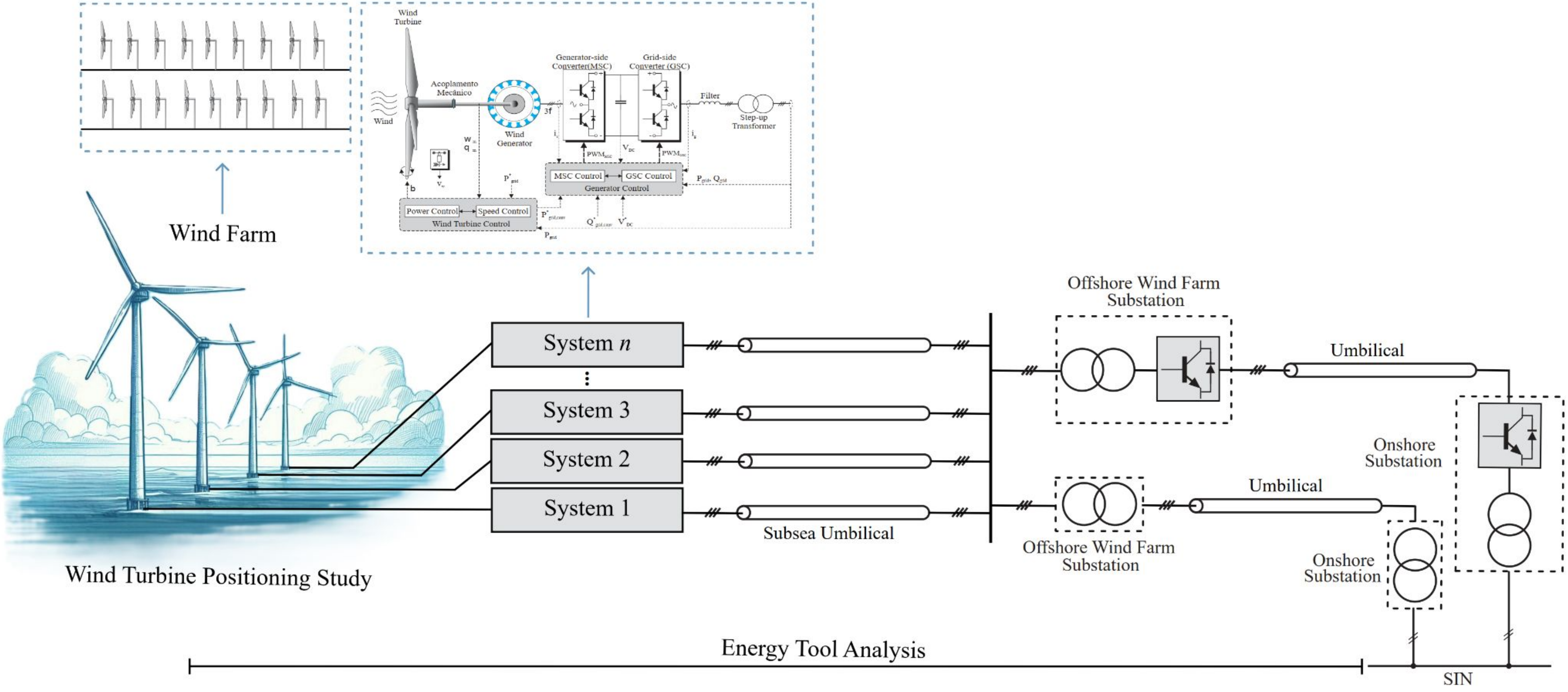




Project: Interconnection Evaluation of an Offshore Wind Generation for a 13.8 kV Electric System Typical of a UEP Libra

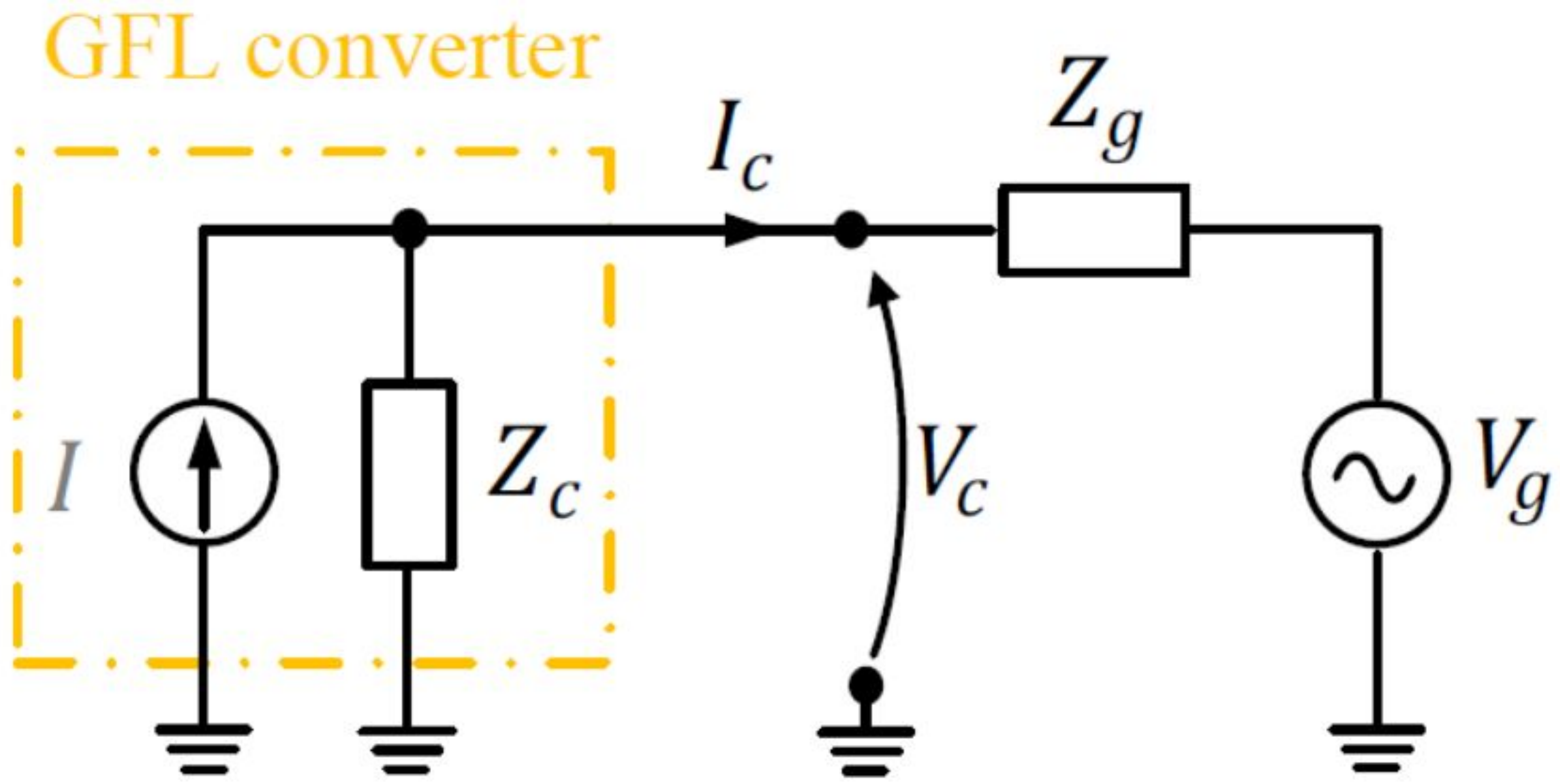
CONTRIBUTIONS TO OFFSHORE WIND SYSTEMS IN THE DEVELOPMENT OF ELECTRICAL MODELS FOR GENERATION, TRANSMISSION AND CONNECTION WITH THE SIN FOR PROJECT STUDIES, ENERGY CAPACITY, OPERATION AND STABILITY

Contributions to Offshore Wind Systems in the Development of Electrical Models for Generation, Transmission and Connection with the SIN for Project Studies, Energy Capacity, Operation and Stability

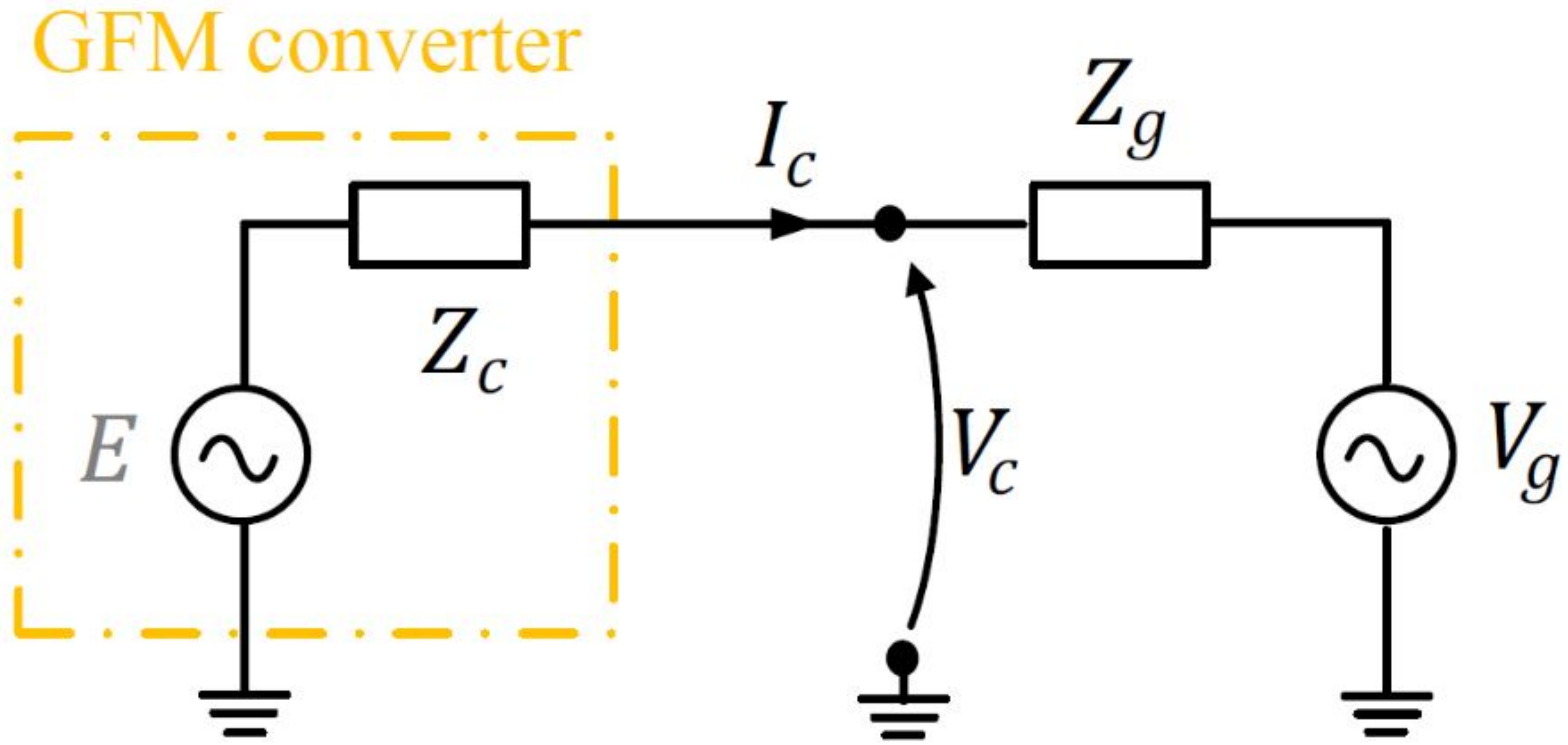


New classification of inverters

- Grid-Following Inverter (GFL)
- Operates as a current source
- Main objective: inject power on the system
- Requirements: Needs a PLL for operation
- Doesn't operate on islanded conditions

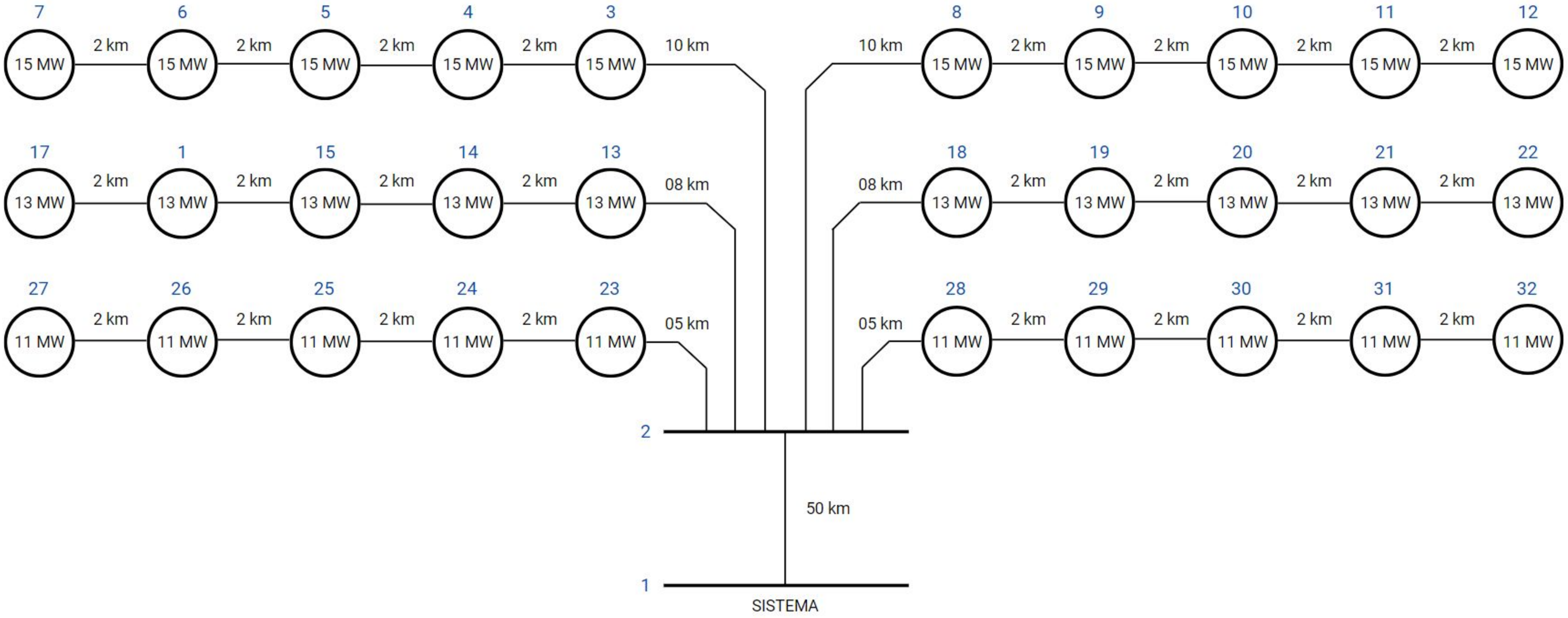


- Grid-Forming Inverter (GFM)
- Operates as a voltage source
- Main objective: improve stability in the grid
- Requirements: Needs a ESS for operation
- Can operate on islanded conditions



Power flow optimization in a Offshore Wind farm

- Proposed case of study:



Results of the optimization

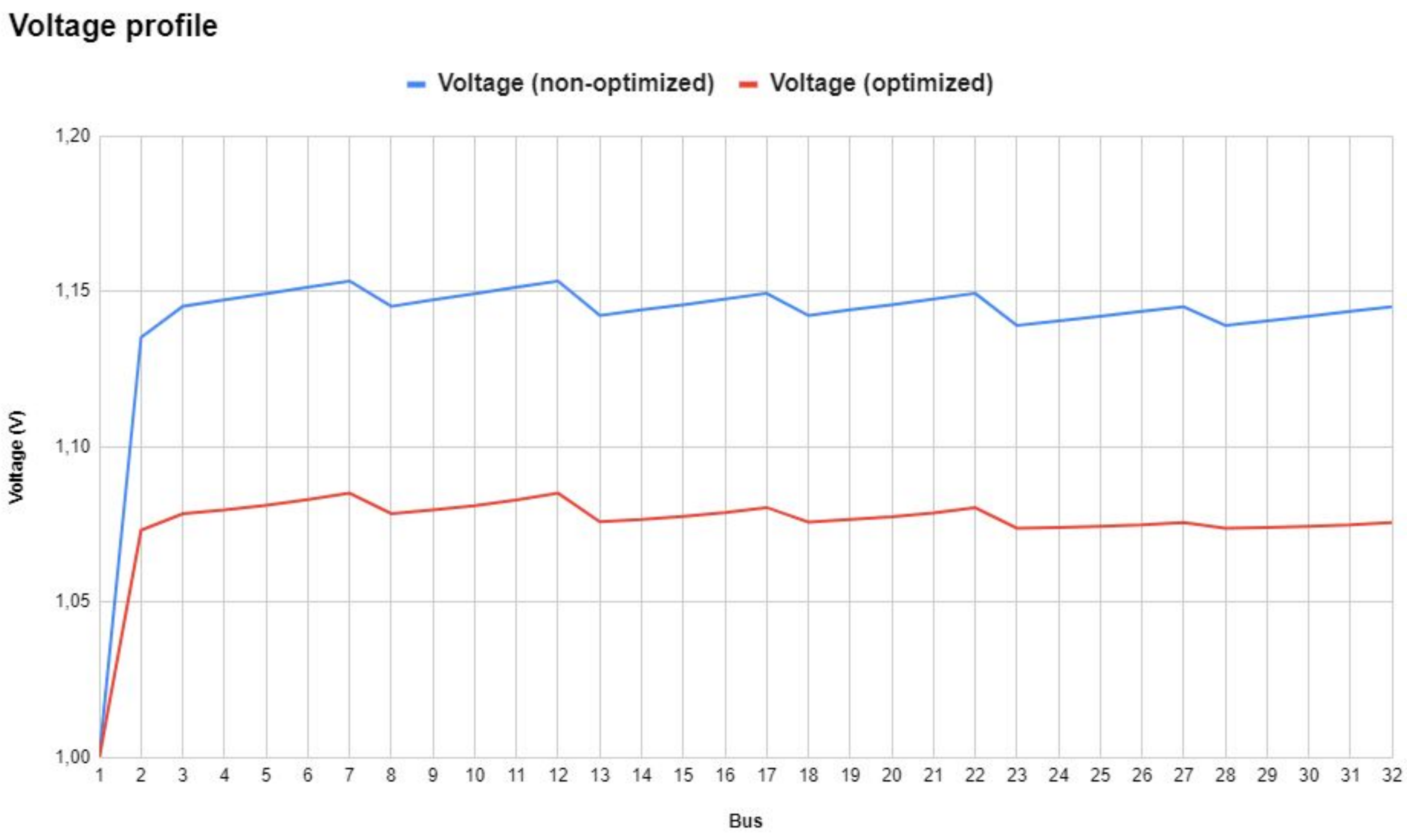
- Non-optimized case:

```
Newton Raphson Load-Flow Study
Report of Optimal Power Flow Calculations

Number of iterations       : 5
Solution time              : 0.001 sec
Total real power (MW)      : 18.235674
```

- Optimized case:

```
Newton Raphson Load-Flow Study
Report of Optimal Power Flow Calculations

Number of iterations       : 5
Solution time              : 0.002 sec
Total real power (MW)      : 16.313195
```

Reduction of 10% in active losses
(1,92 MW in losses)



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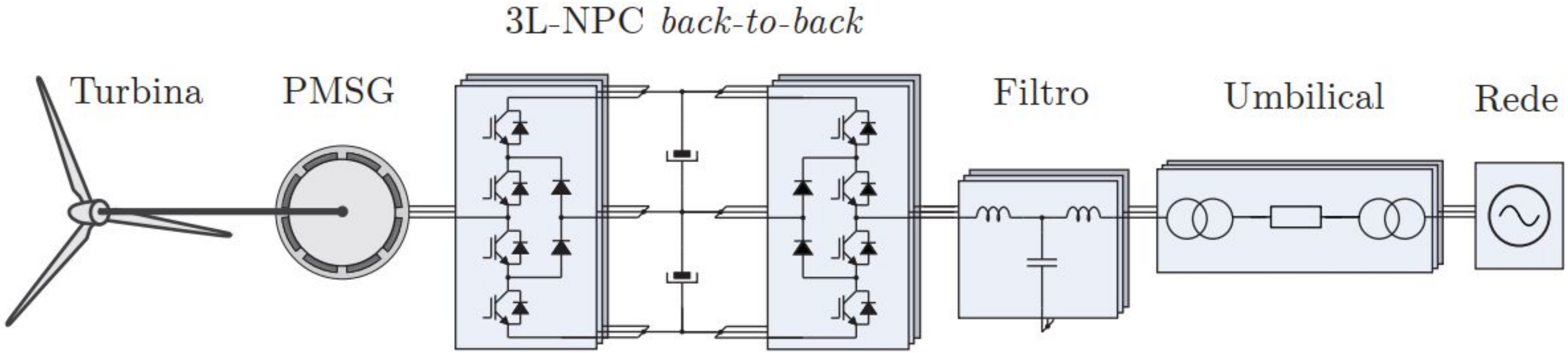
Methodologies for Designing Frequency Controllers in Offshore Wind Energy Conversion Systems Connected to Isolated Grids



Turbina	PMSG	Converter (generator side)	DC link	Converter (grid side)	Filtro	Umbilical
16 MW 5 – 7,6 rpm 10,59 m/s	15,2 MW 4,77 kV 0,84 PF	18 MVA 4,77 kV 900 Hz (f_s) 12,6 Hz (f_o)	7,2 kV	18 MVA 3,5 kV 900 Hz (f_s) 60 Hz (f_o)	LCL + RC	30 kV / 400 mm^2 10 km / 50 km

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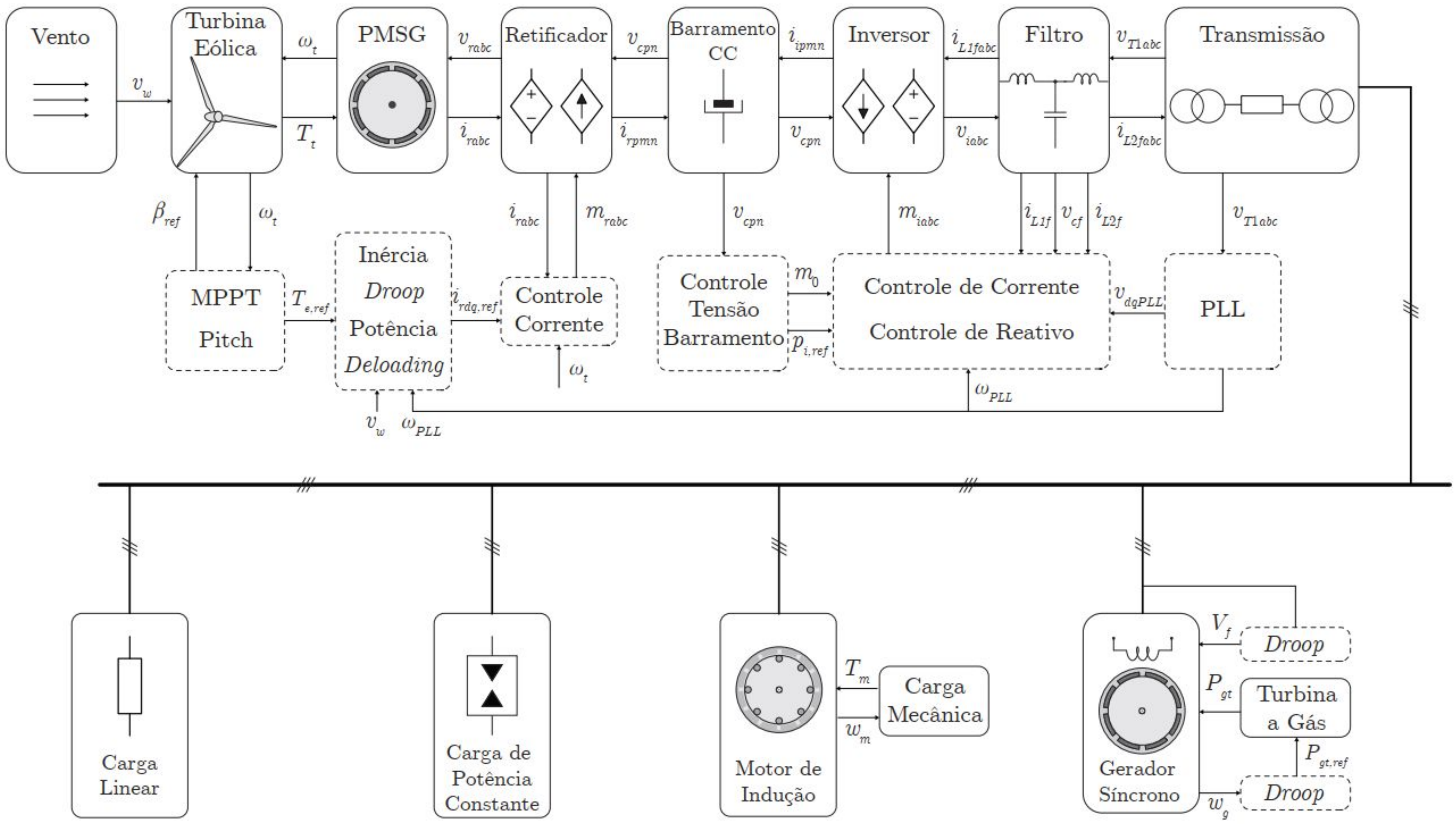
System Diagram



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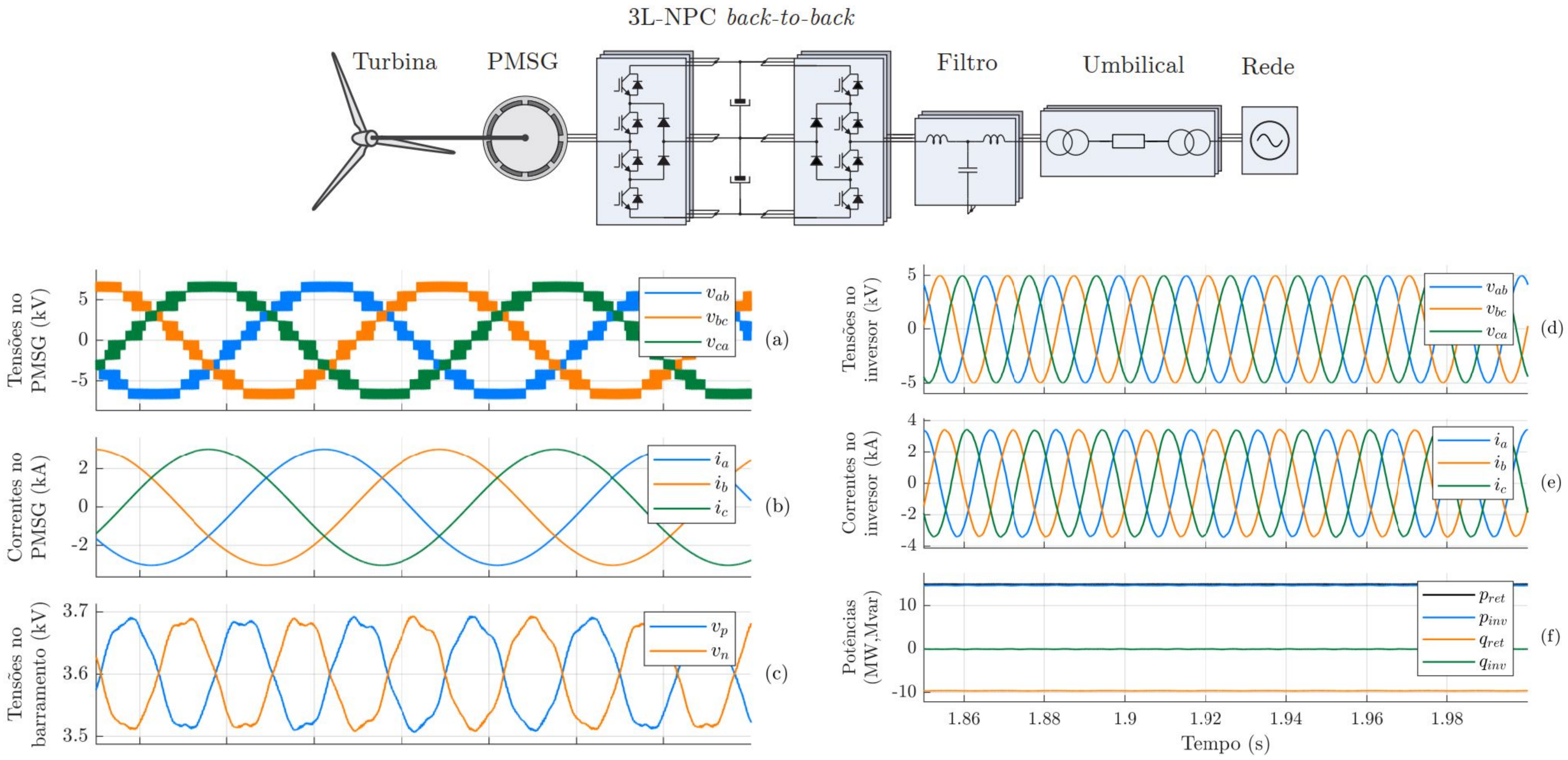
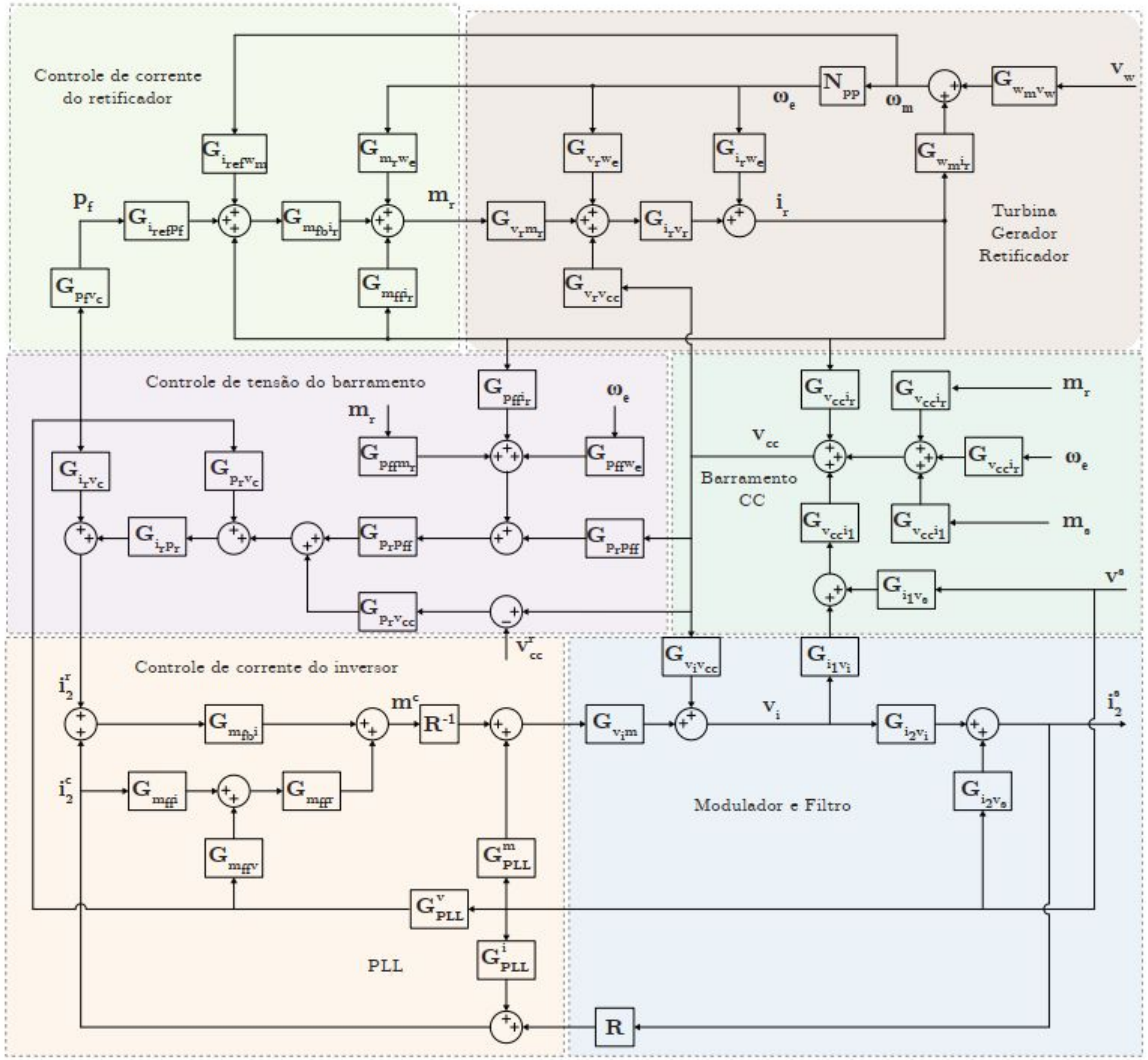
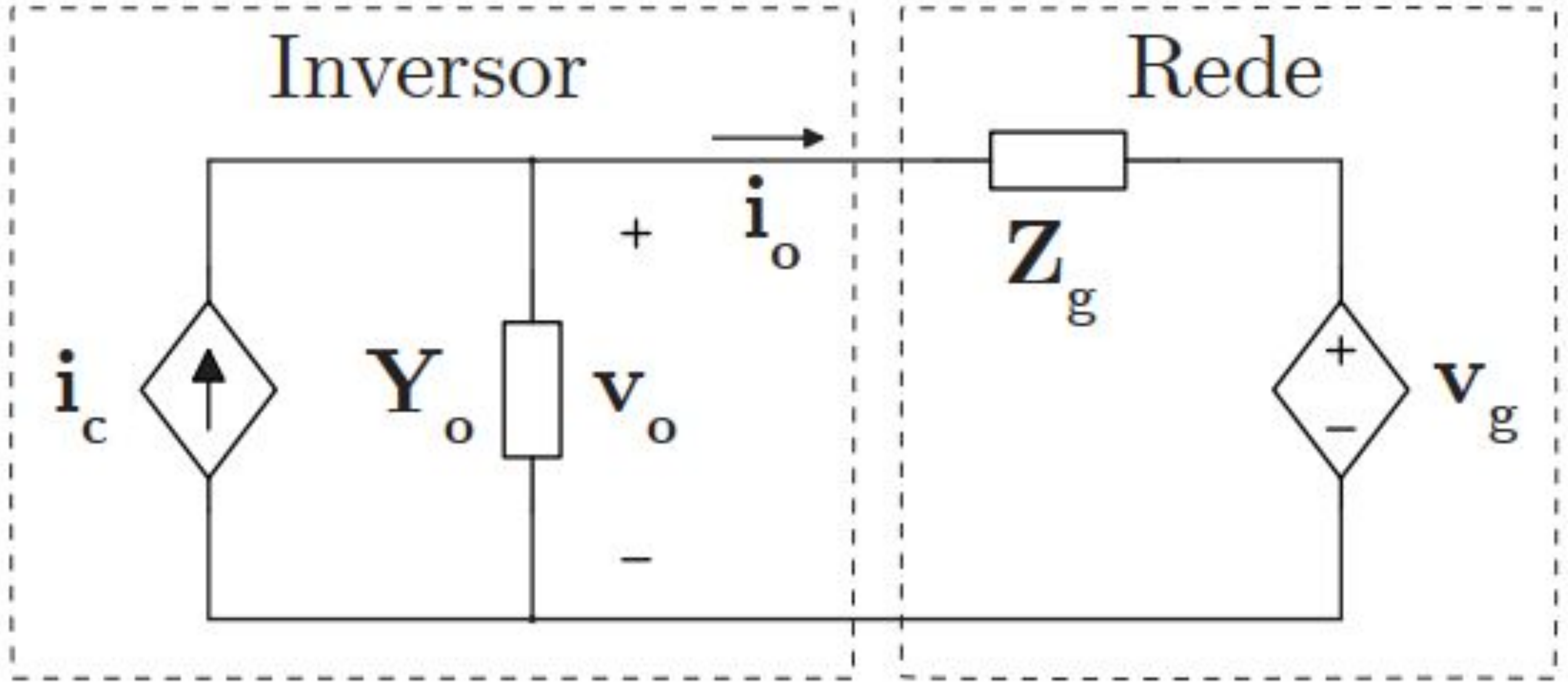
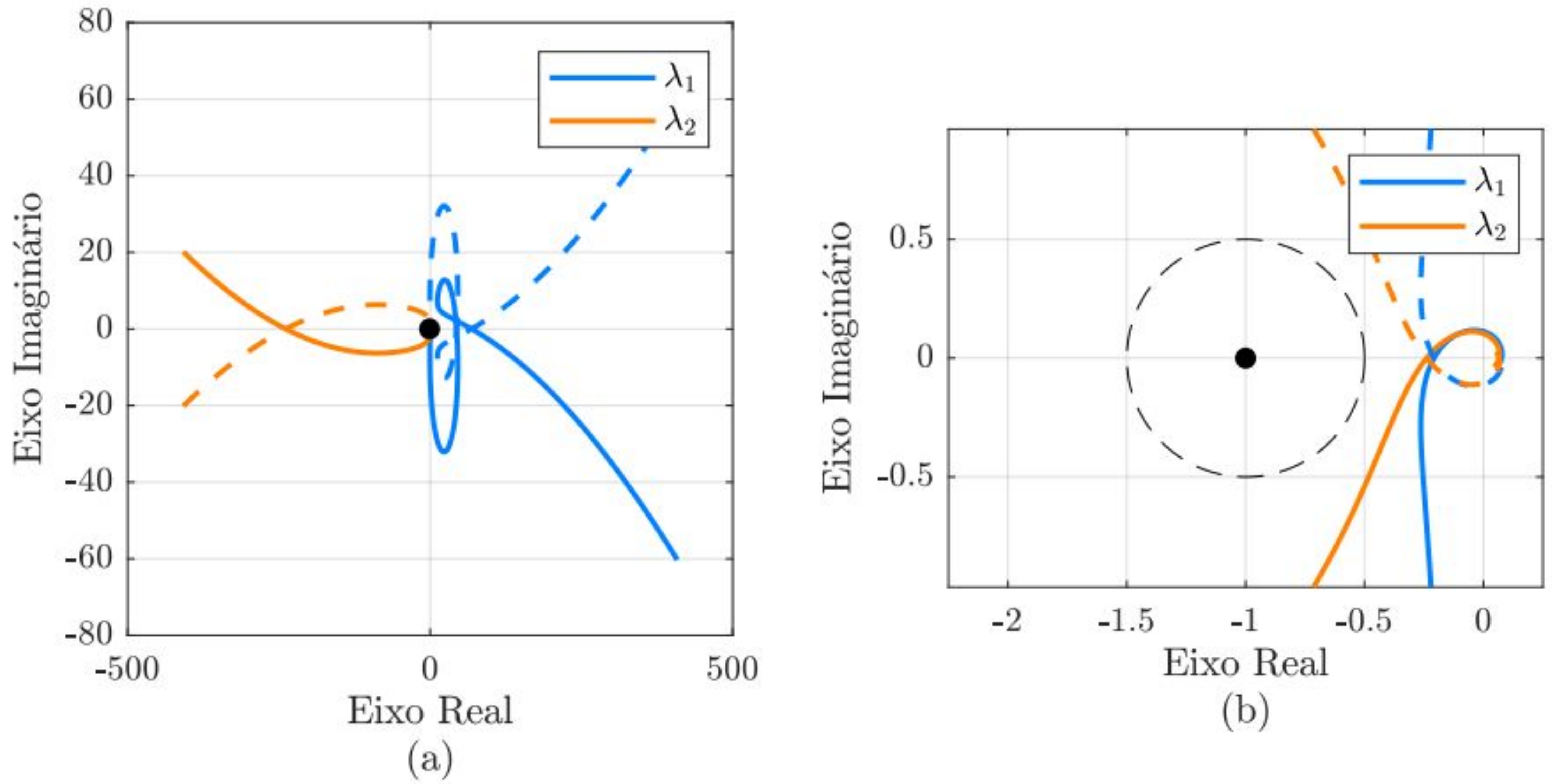
Operation in Permanent Regime



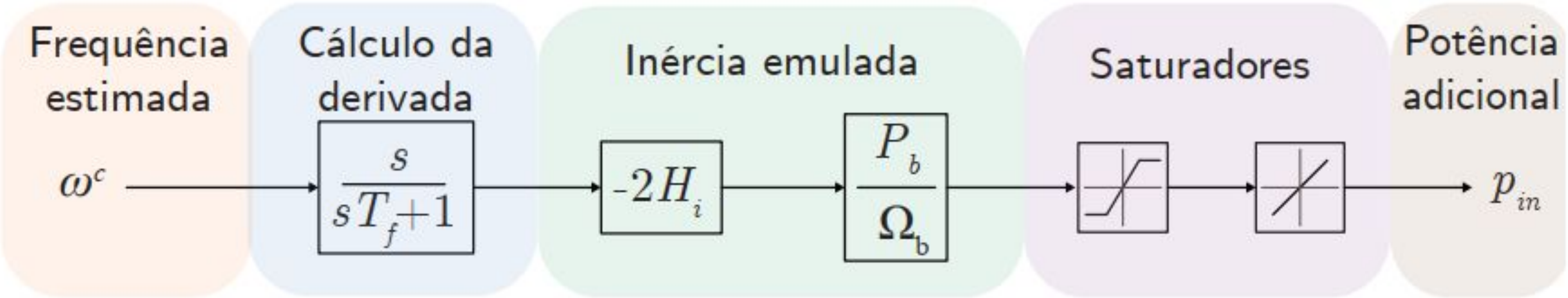
Static Stability



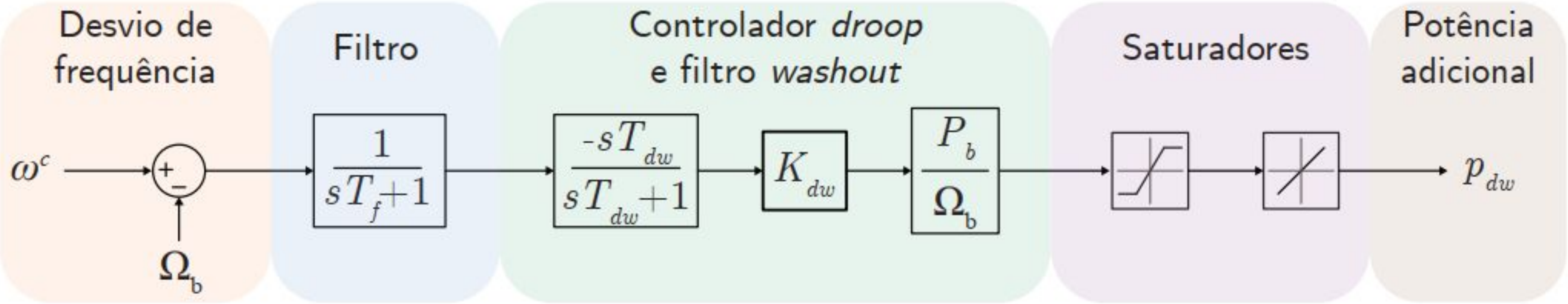




- Virtual Inertia:

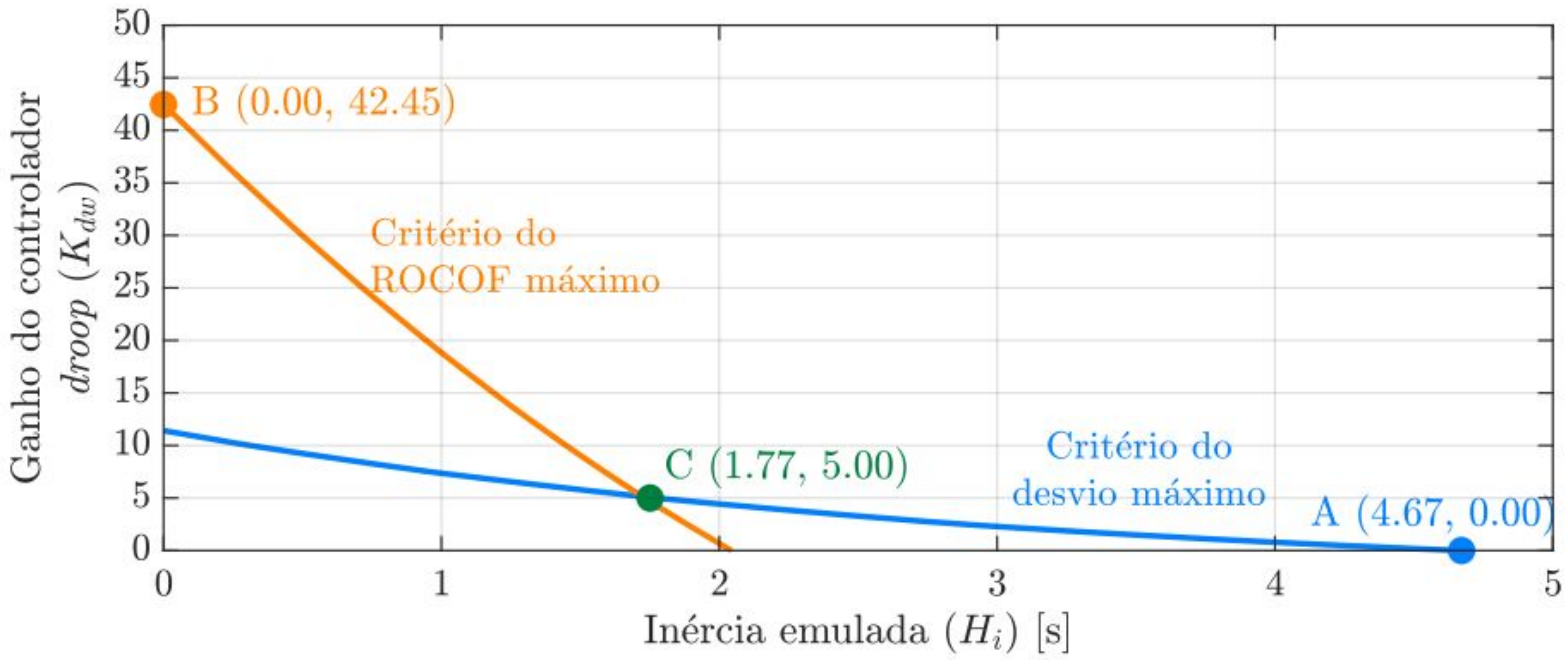


- Droop-Washout:

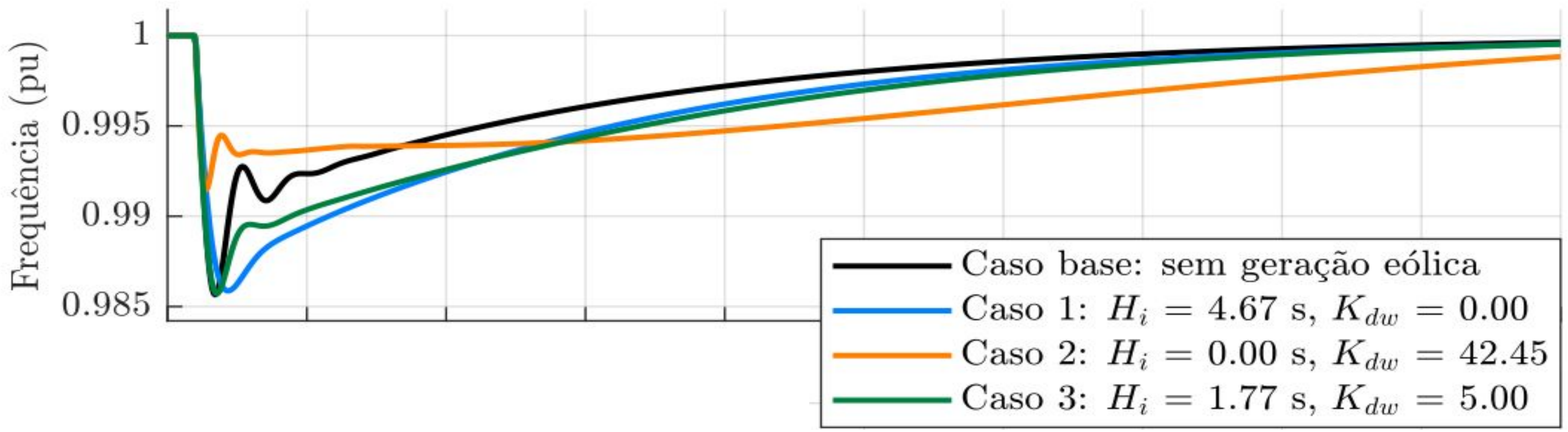


Case study – Grid with 25% wind generation

- Requirements:
  - Maximum RoCoF;
  - Maximum frequency deviation.

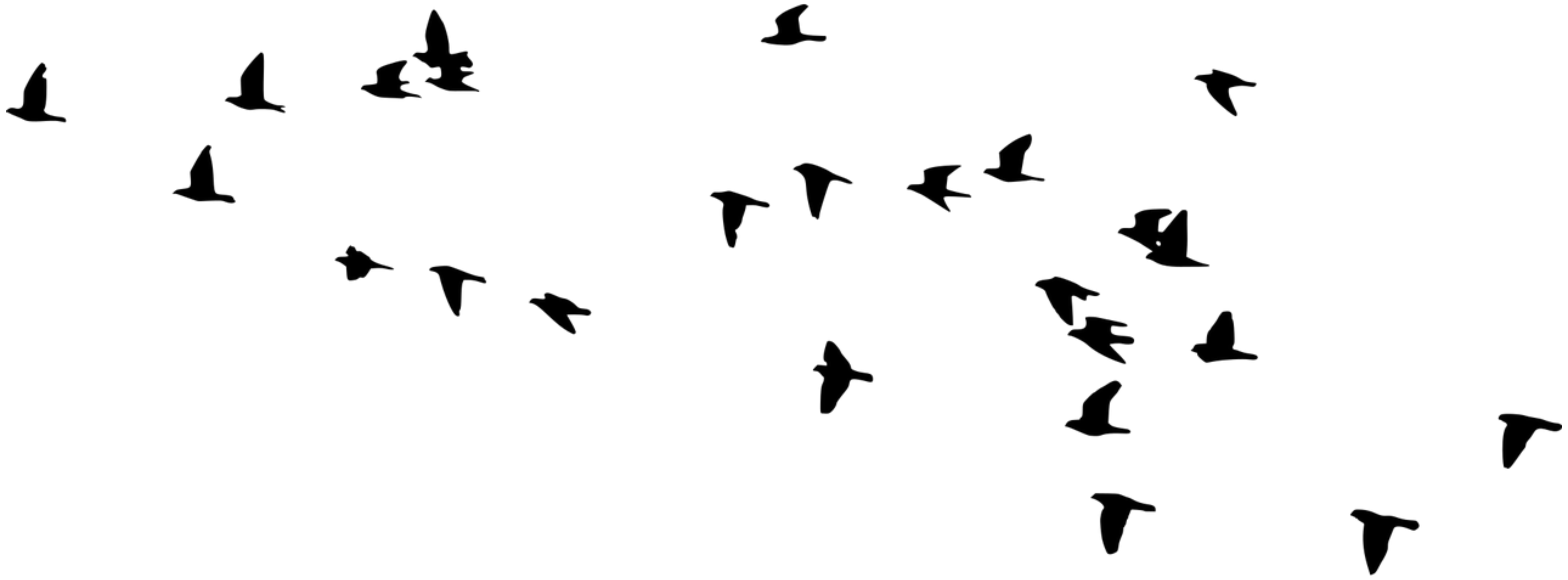


- Event with active power step in the system:



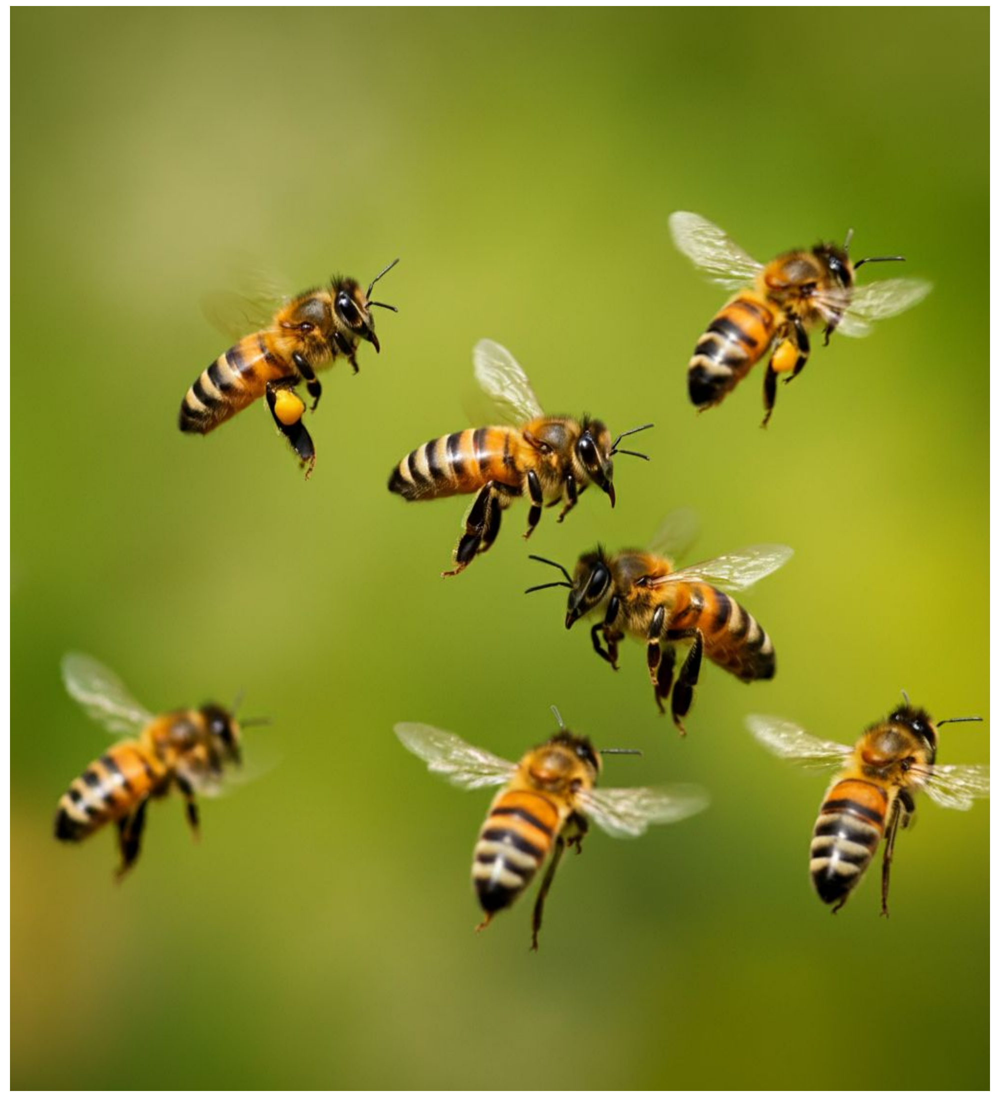
Control Optimization

- Use of meta-heuristic optimization algorithms to tune the gains of PI controllers that compose the field oriented control (FOC) approach;
  - Reduce the dependency of the control designer experience with the system and controller, facilitating the control tuning process;
- Most swarm intelligence algorithms are global optimization techniques inspired by patterns of animals in nature (migration, reproduction, foraging, defense, hunting, among other behaviors).



Control Optimization

- **Algorithms implemented at the core of this procedure:** bat optimizer, artificial bee colony, grasshopper optimization algorithm, and black-winged kite optimizer.

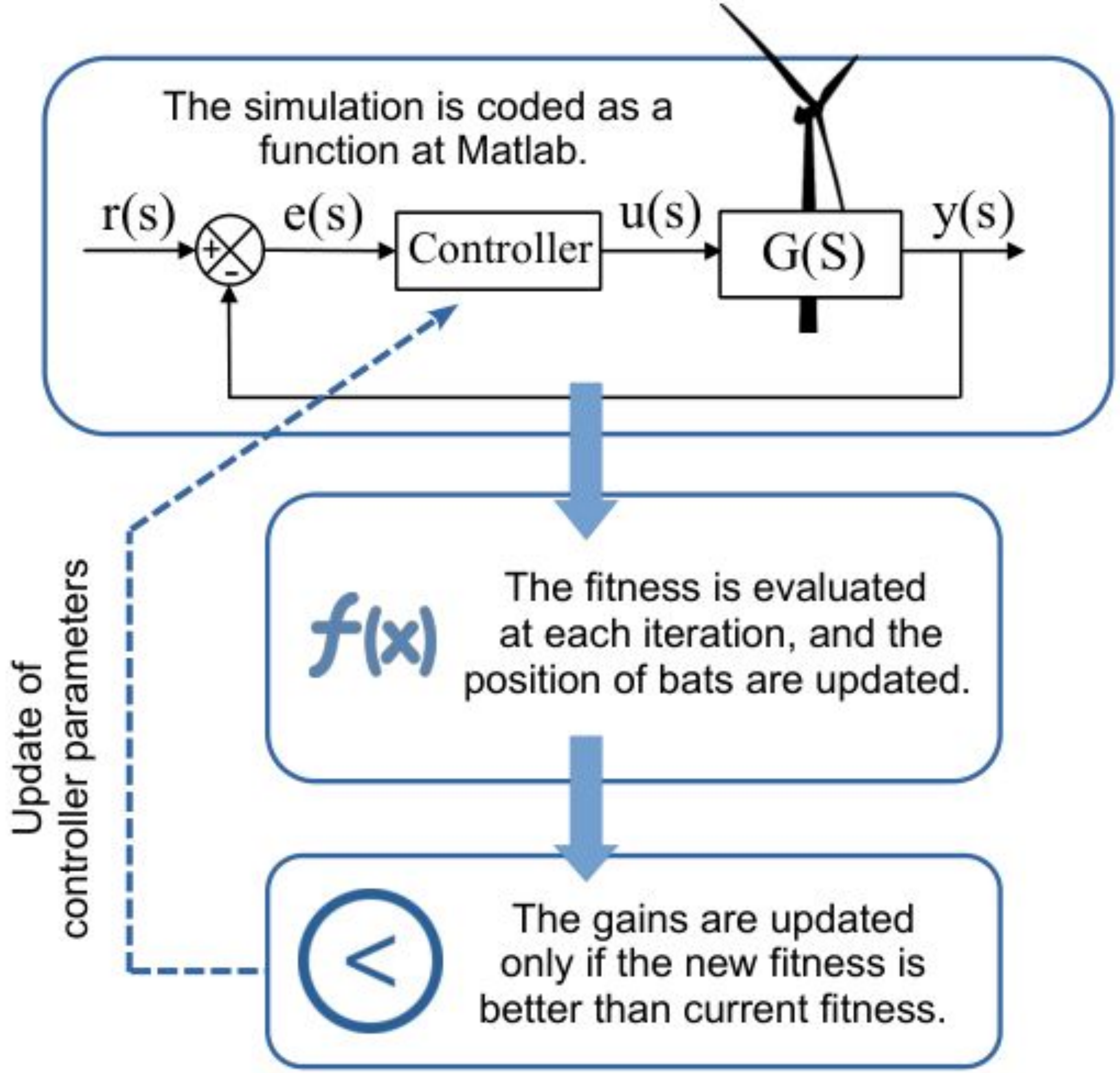



Control of current in long subsea transmission cables

- Offshore wind energy conversion systems (WECS) need long transmission cables to transport the power generated far from the coast;
- Long subsea transmission cables are used for this task. However, they generate stability issues when interacting with the electrical grid;
- The longer the cable, the more resonances arise.

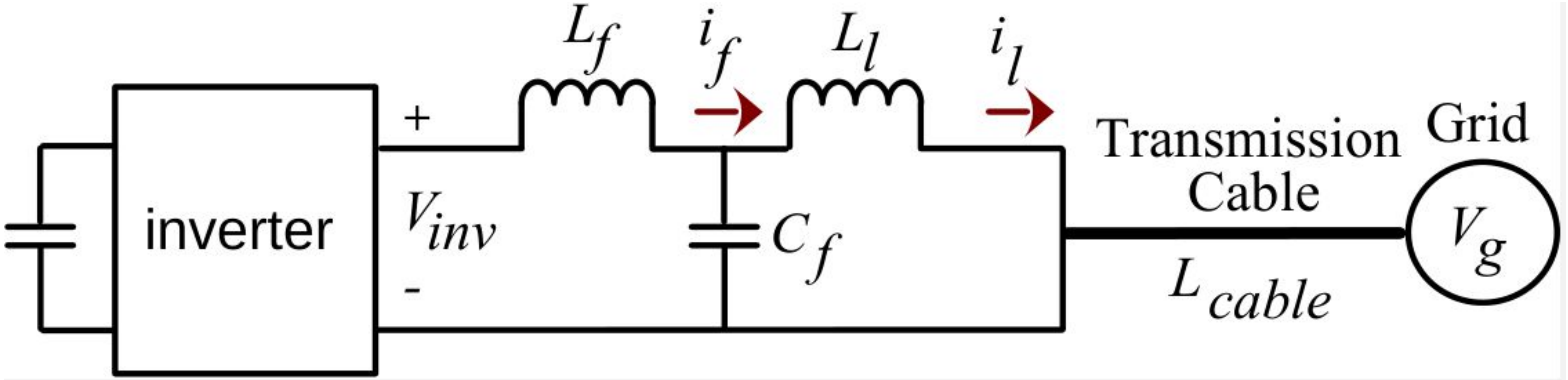
Control Optimization

- Swarm intelligence optimizers are abstract algorithms. Therefore, systematic rules must be designed to drive the optimization procedure:
  1. Relate the engineering problem with the mimetization performed by the optimizer;
  2. The fitness function must consider the current tracking errors in dq axes. Thus, the best solution is that whose gains most minimize the overall tracking errors;
  3. If a set of gains make the control action requires more voltage than the available DC link voltage, then the fitness function has to be penalized, ensuring the exclusion of unfeasible solutions.



Control of current in long subsea transmission cables

- The literature of control for this subsystem of WECS is very reduced:
  - The current solutions are designed for specific conditions, and they consider some simplifications to design classical controllers;
  - Besides, the literature is composed exclusively of multi-loop control systems.

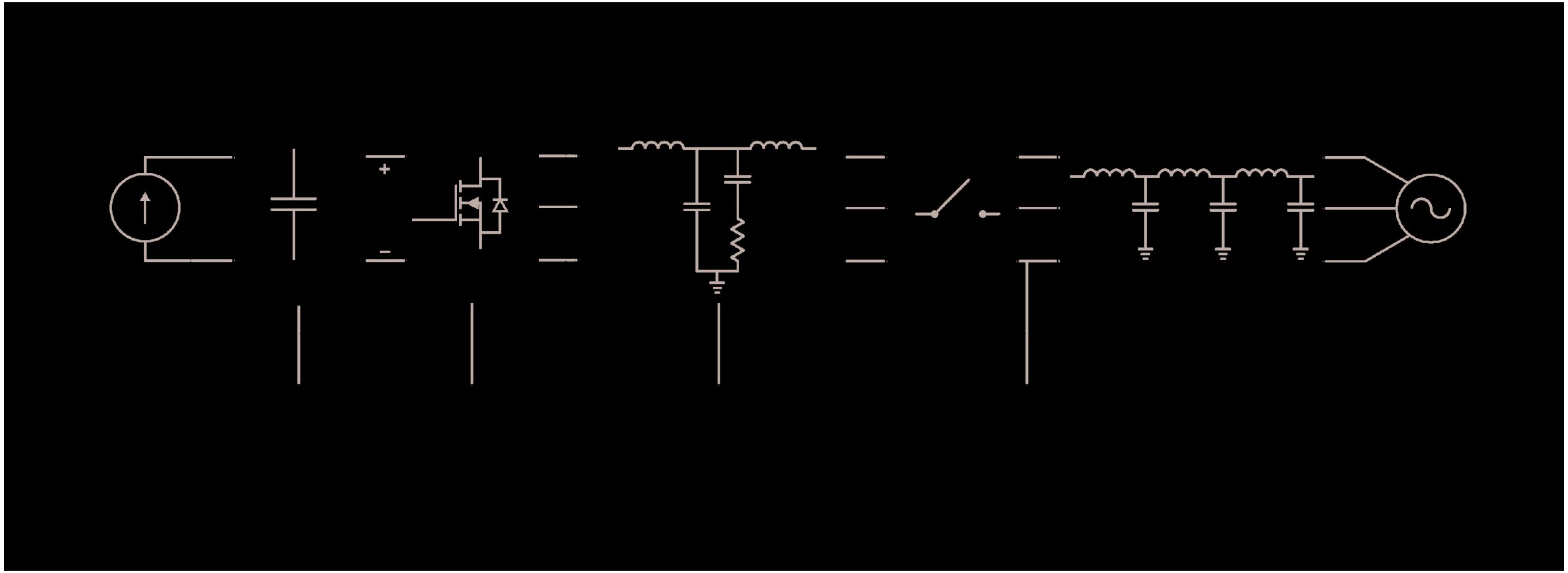


Control of current in long subsea transmission cables – Developed solutions

- Single-loop robust adaptive controllers to regulate the current flowing in these cables with the ability to damp the resonance peaks inherent to these systems;
  - The adaptive control strategies are generalizable for any cable length (model free), and they do not depend on knowledge of the system parameters.
  - The only information required to design the controller is the cable length to configure the number of rejection terms in the controller (a pair of adaptive gains for each resonance);
  - It avoids the addition of passive elements to the system structure, reducing power loss.

Experimental Setup

- Prototype characteristics:
  - 900 Hz PWM
  - LCL filter with passive dumping.
  - A Filter Board for the grid and the VSI interface and the current/voltage measurements.
  - Grid: 127 V Phase / 220 V Line / 60 Hz
  - A SEMIKRON module with the dc bus, a three phase VSI with IGBT Modules, and gate drivers.
  - A Signal Conditioning Board for the control, the PWM generationing and serial comunication.



INEP

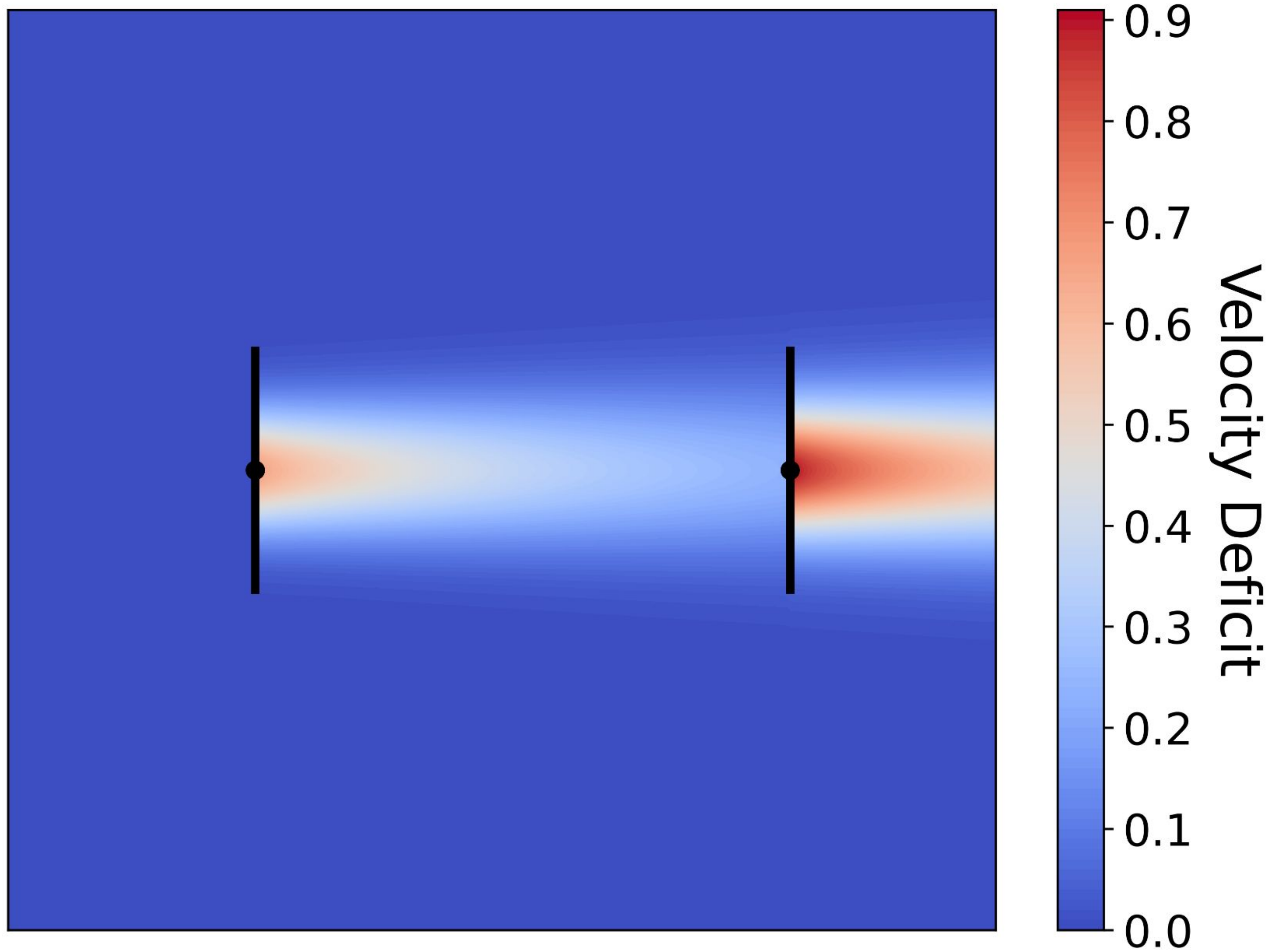
Experimental Setup

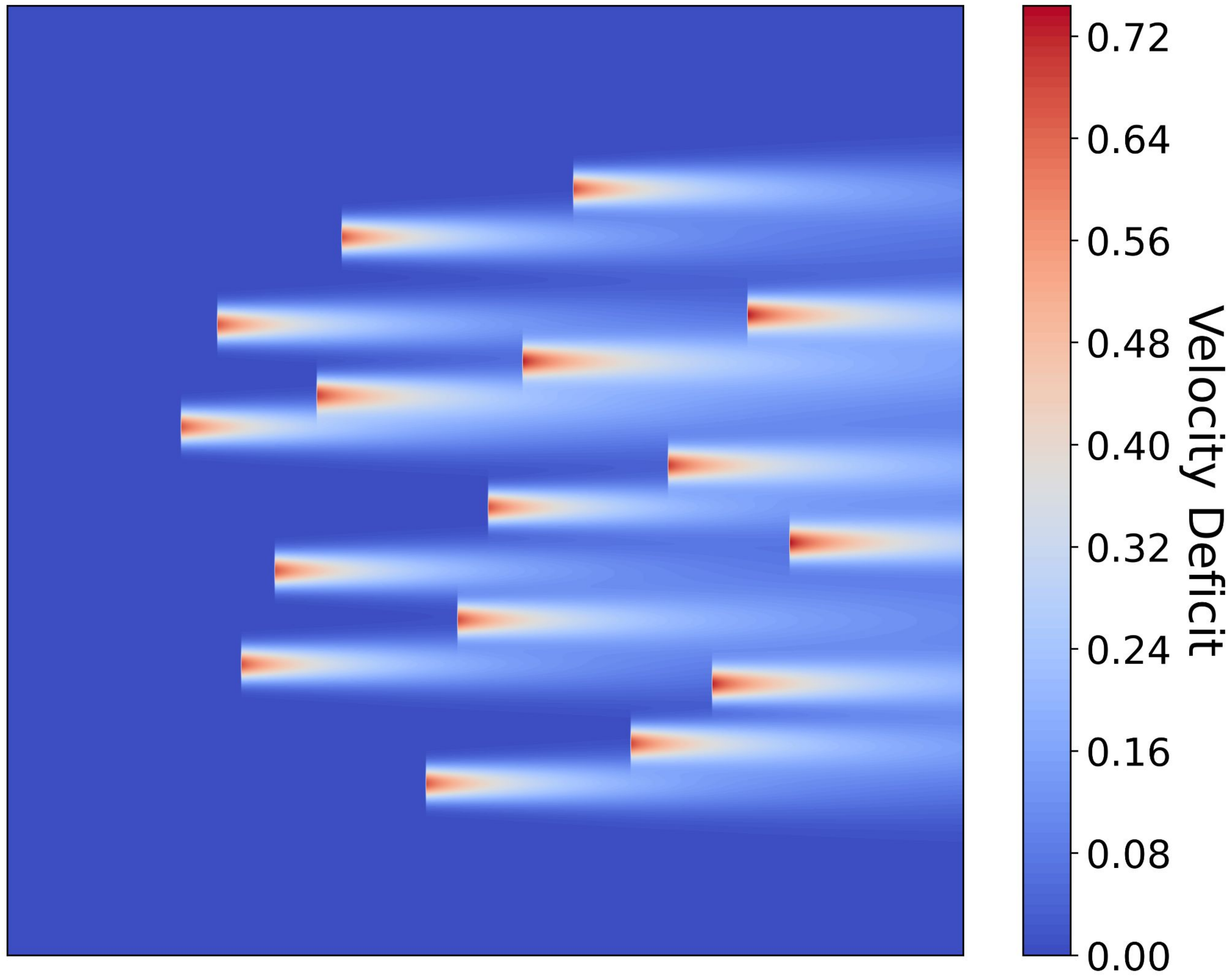
- Wind farm Teste Setup:
  - Two prototypes with serial communication.
  - Each Wind Turbine can inject power into the grid.
  - The control can regulate the power injected into the grid by each prototype.

AI-Driven Analysis for Offshore Wind Farm Projects

UFSC

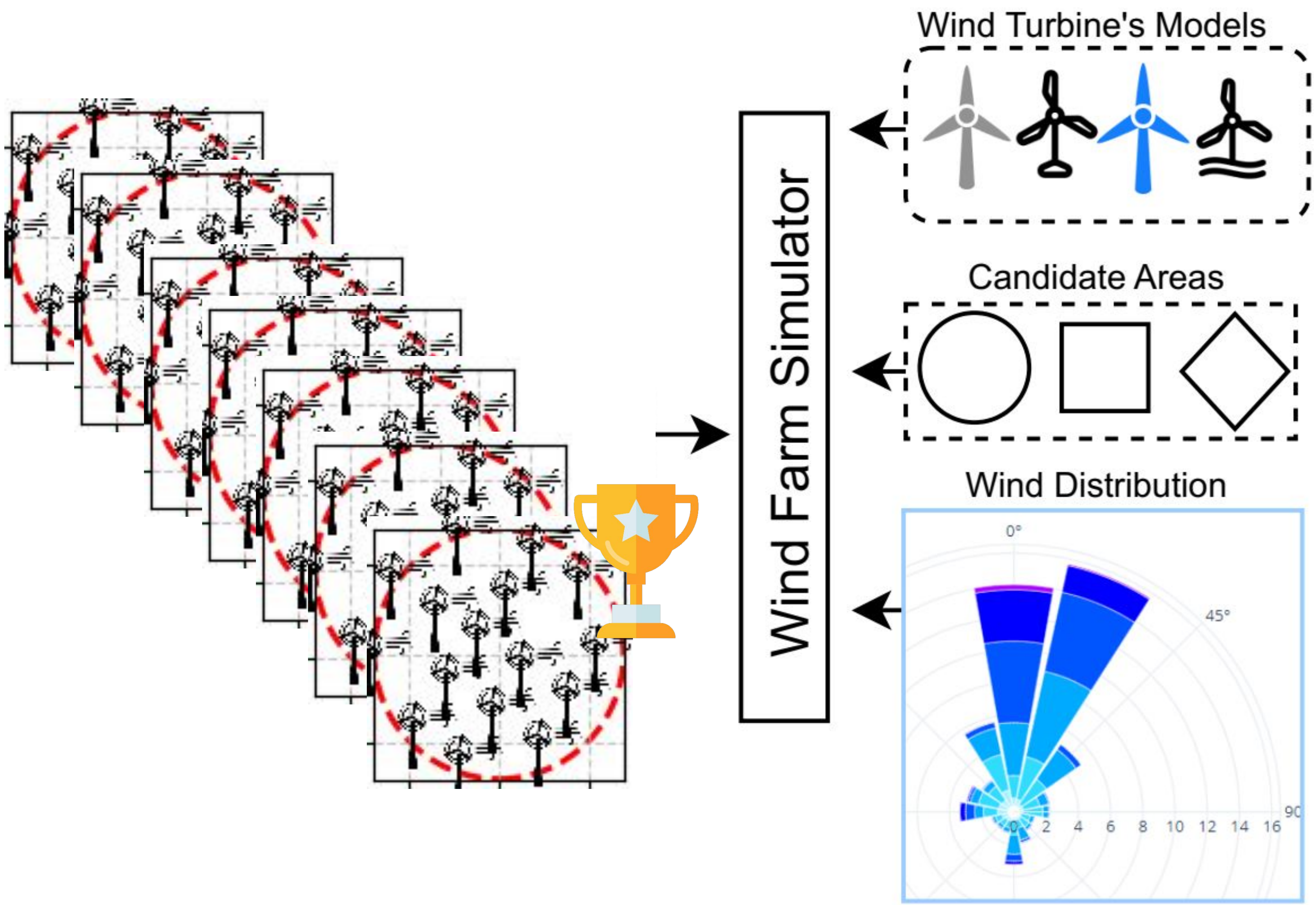
- Optimization problem for wind farms layouts
  - Maximize AEP
  - Minimize wake effect, implantation cost (cabling, etc.).





AI-Driven Analysis for Offshore Wind Farm Projects

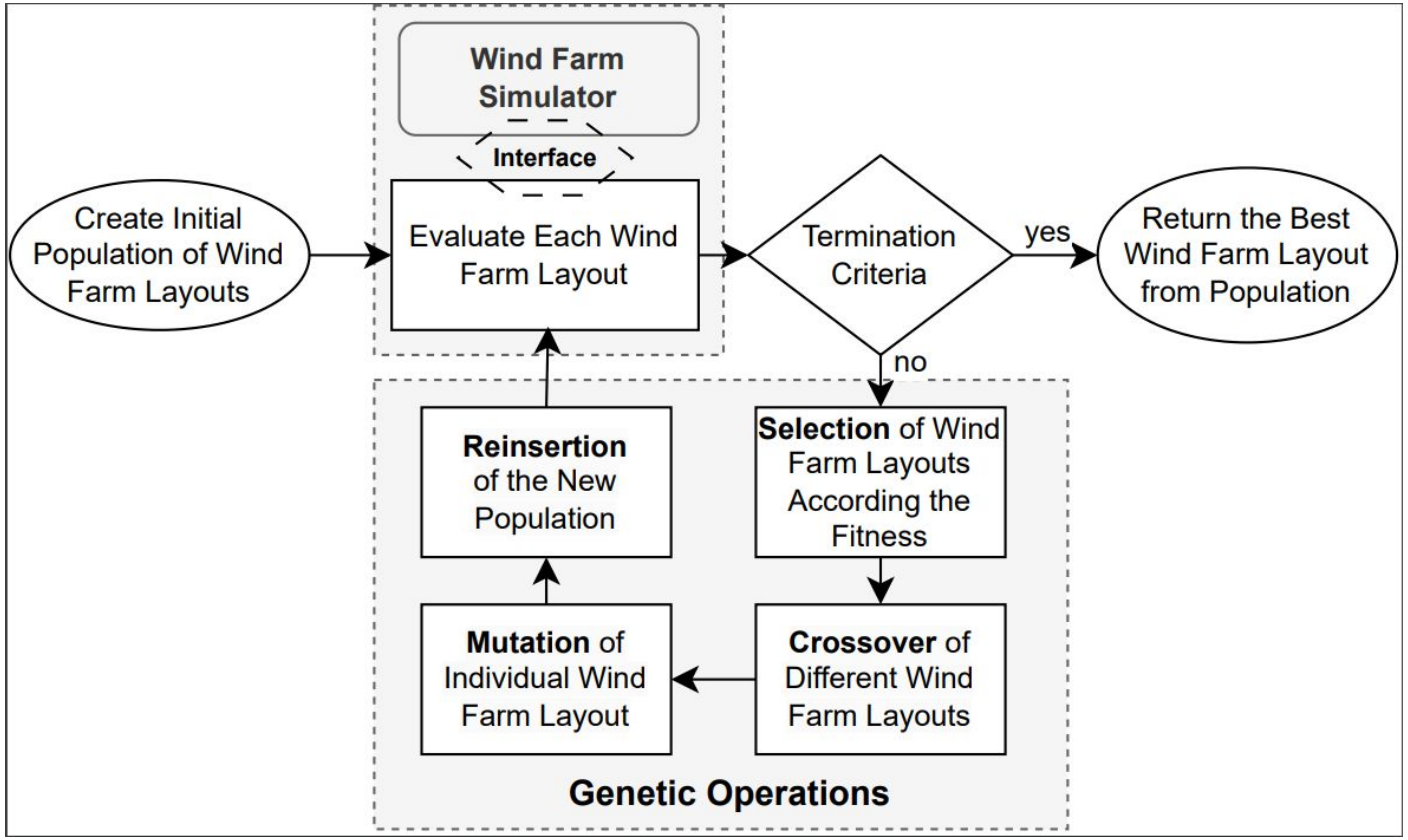
- Modular Framework
  - Turbine models (wake effects)
  - Area constraints
  - Wind probability distribution
  - Candidate layouts

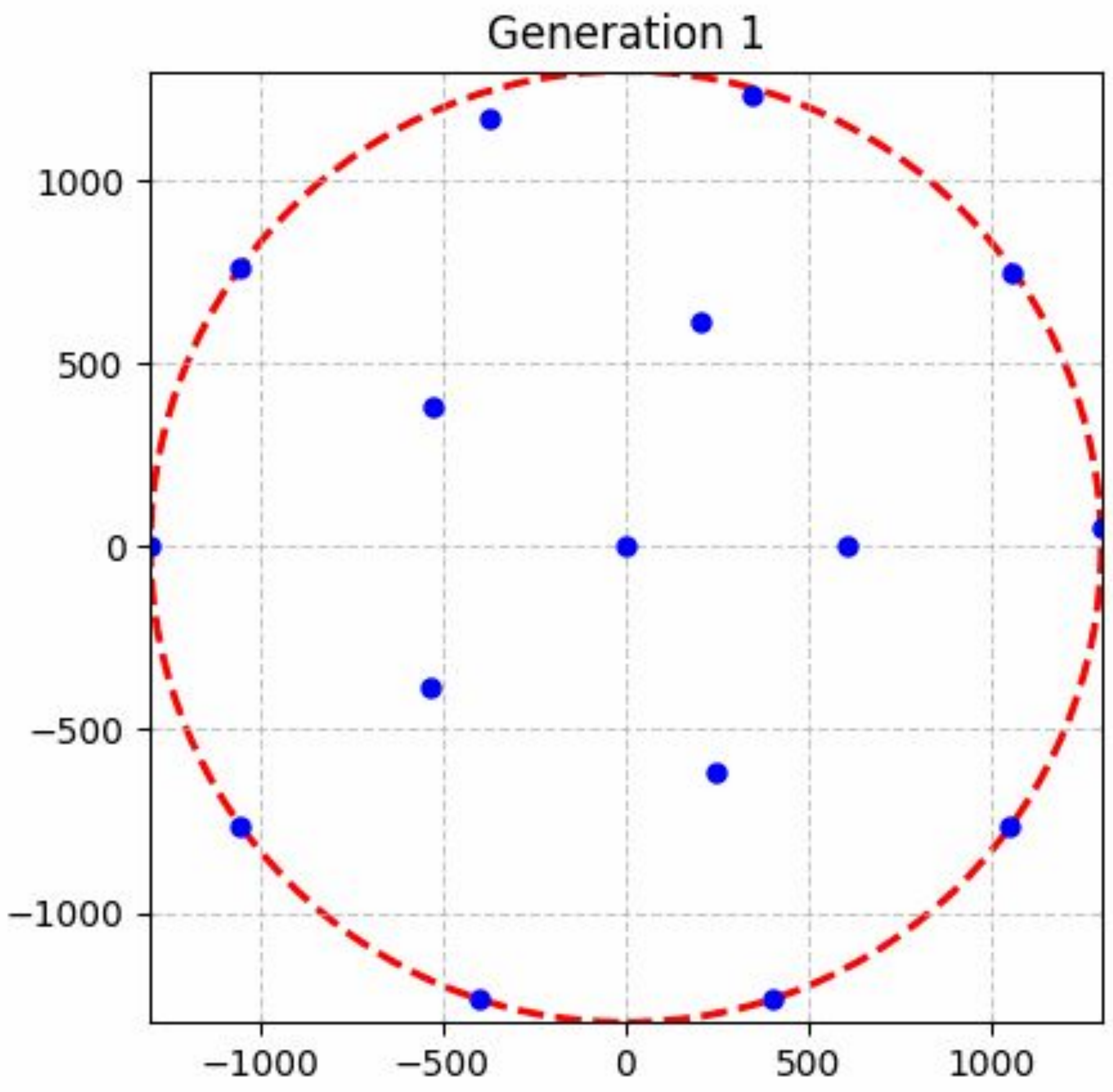


INEP

AI-Driven Analysis for Offshore Wind Farm Projects

- Current progress: Genetic Algorithms for Layout Optimization to Maximize AEP.





AI-Driven Analysis for Offshore Wind Farm Projects

- It shows good results!
- Future work:
  - Multidisciplinar;
  - Multiple optimization variables.

Table 3: Turbine scenario participant results for 16 turbines.

Rank	Algorithm	Grad.	AEP (MWh)	Increase
1	SNOPT+WEC	G	418,924.4064	14.17%
2	Simple Evolutionary Strategy	GF	416,897.7293	13.61%
3	fmincon	G	414,141.2938	12.86%
4	SNOPT	G	412,251.1945	12.35%
5	SNOPT	G	411,182.2200	12.06%
6	Preconditioned Sequential Quadratic Programming	G	409,689.4417	11.65%
7	Multistart Interior-Point	G	408,360.7813	11.29%
8	Full Pseudo-Gradient Approach	GF	402,318.7567	9.64%
9	Basic Genetic Algorithm	GF	392,587.8580	6.99%
10	Simple Particle Swarm Optimization	GF	388,758.3573	5.95%
11	Simple Pseudo-Gradient Approach	GF	388,342.7004	5.83%
12	(Example Layout)	-	366,941.5712	-

Table 4: Turbine scenario participant results for 36 turbines.

Rank	Algorithm	Grad.	AEP (MWh)	Increase
1	SNOPT+WEC	G	863,676.2993	17.05%
2	Simple Evolutionary Strategy	GF	854,895.9156	15.85%
3	Multistart Interior-Point	G	851,631.9310	15.42%
4	Preconditioned Sequential Quadratic Programming	G	849,369.7863	15.11%
5	SNOPT	G	846,357.8142	14.70%
6	SNOPT	G	844,281.1609	14.42%
7	Full Pseudo-Gradient Approach	GF	828,745.5992	12.31%
8	fmincon	G	820,394.2402	11.18%
9	Simple Pseudo-Gradient Approach	GF	813,544.2105	10.25%
10	Basic Genetic Algorithm	GF	777,475.7827	5.37%
11	Simple Particle Swarm Optimization	GF	776,000.1425	5.17%
12	(Example Layout)	-	737,883.0985	-

Table 5: Turbine scenario participant results for 64 turbines.

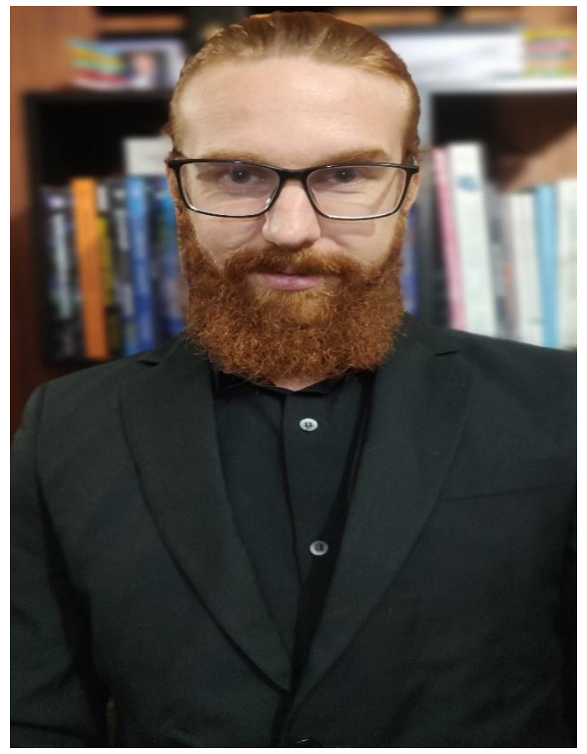
Rank	Algorithm	Grad.	AEP (MWh)	Increase
1	SNOPT+WEC	G	1,513,311.1936	16.86%
2	Preconditioned Sequential Quadratic Programming	G	1,506,388.4151	16.36%
3	Multistart Interior-Point	G	1,480,850.9759	14.35%
4	Simple Evolutionary Strategy	GF	1,479,753.2366	14.26%
5	SNOPT	G	1,476,689.6627	14.03%
6	Full Pseudo-Gradient Approach	GF	1,455,075.6084	12.36%
7	SNOPT	G	1,445,967.3772	11.66%
8	Simple Pseudo-Gradient Approach	GF	1,422,268.7144	9.82%
9	Simple Particle Swarm Optimization	GF	1,364,943.0077	5.40%
10	fmincon	G	1,336,164.5498	3.18%
11	Basic Genetic Algorithm	GF	1,332,883.4328	2.93%
12	(Example Layout)	-	1,294,974.2977	-

Project: Contributions to Offshore Wind Systems in the Development of Electrical Models for Generation, Transmission and Connection with the SIN for Project Studies, Energy Capacity, Operation and Stability

UFSC

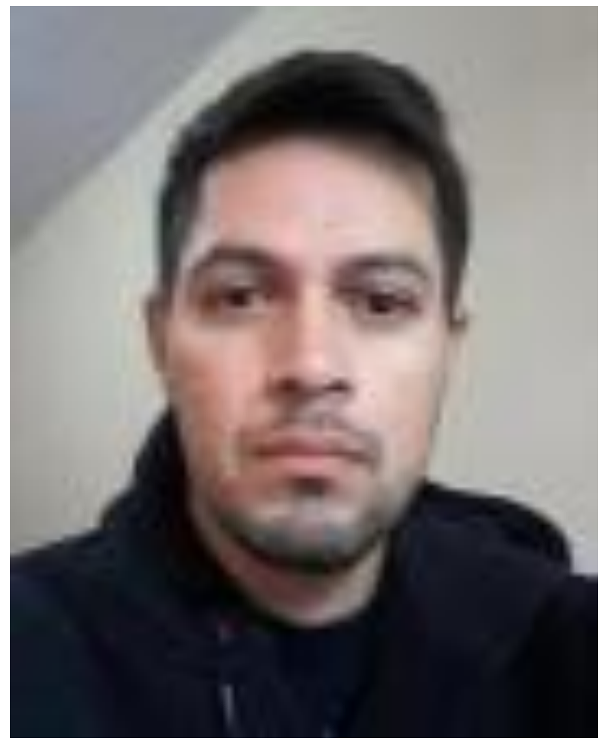
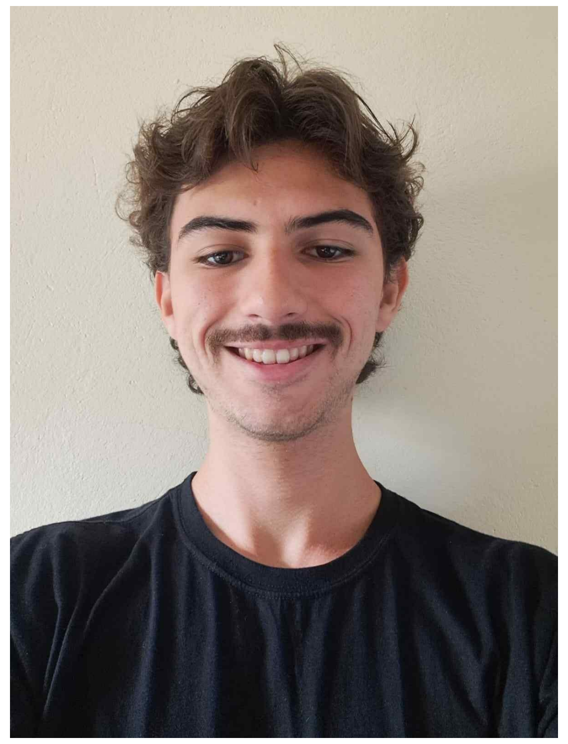
CNPq








INEP

Continuation of the Electrical Studies

1.Energy Tool Analysis, Simulation, Emulation:

Energy Tool Analysis: mathematical analysis (statistics) of how much energy will be delivered to the platform considering the wind profile, all components and its limitation and the efficiency of the wind system (steady state behavior).

Simulation: electrical models representing the wind system (dynamics and steady state behaviors).

Emulation: real time simulation (OPAL).

2. Use new wind measurement data (LIDAR) in the already developed energy tool:

Process the data: data processing (sample, filter, spectrum, complete data).

Wind characteristics: intermittency, profile, generation capacity.

Generation forecast: machining leaning (wind, pressure, temperature, etc), dispatch decisions.

3. Real wind measure + Energy Tool Analysis

Active power and energy delivery

Capacity factor

Analyze generation: hour, day, month and year

Study of storage systems integrated with WECs: different time constants - minutes, hours, and day

Environment issues and Equivalent CO2

Continuation of the Electrical Studies

4. Real wind measure + Simulation models

Operation analysis: dynamics and steady state behaviors

Stability analysis

Propose operating protocols: define rules for connecting wind power plants. Define crucial strategies for testing and validating WTG and WPPs concerning FPSO compliance and connection requirements.

Products delivered to the platform: energy and services.

5. Wind farm.

Wind farm turbine connection studies.

Optimal number of turbines: in terms of generation, stability and CAPEX

Stability analysis

Wind turbine positioning study: optimization study

6. Distance:

Long: transmission study, size, number of turbines, capex;

Short: capex of installation;

Continuation of the Electrical Studies

7. Real time simulation (OPAL).

System models and real time simulation;

Define crucial strategies for testing and validating WTG and WPPs concerning.

8. Digital Twin

Aiming to leverage models, test benches, historical testing and operational data, and artificial intelligence to aid in the design and operation of wind turbines and power plants.

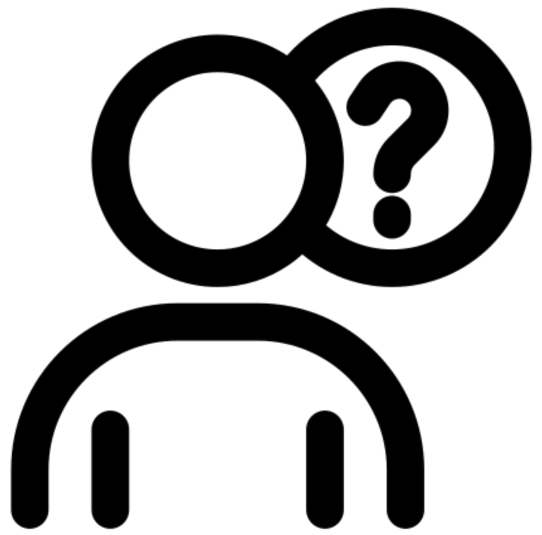
To monitor, predict, or simulate its behavior and performance

9. Add energy storage systems

Evaluate the use of energy storage systems to mitigate the intermittent problem characteristic of wind generation and contribute with other services to the grid.

Thank you!

Open to discussions!



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