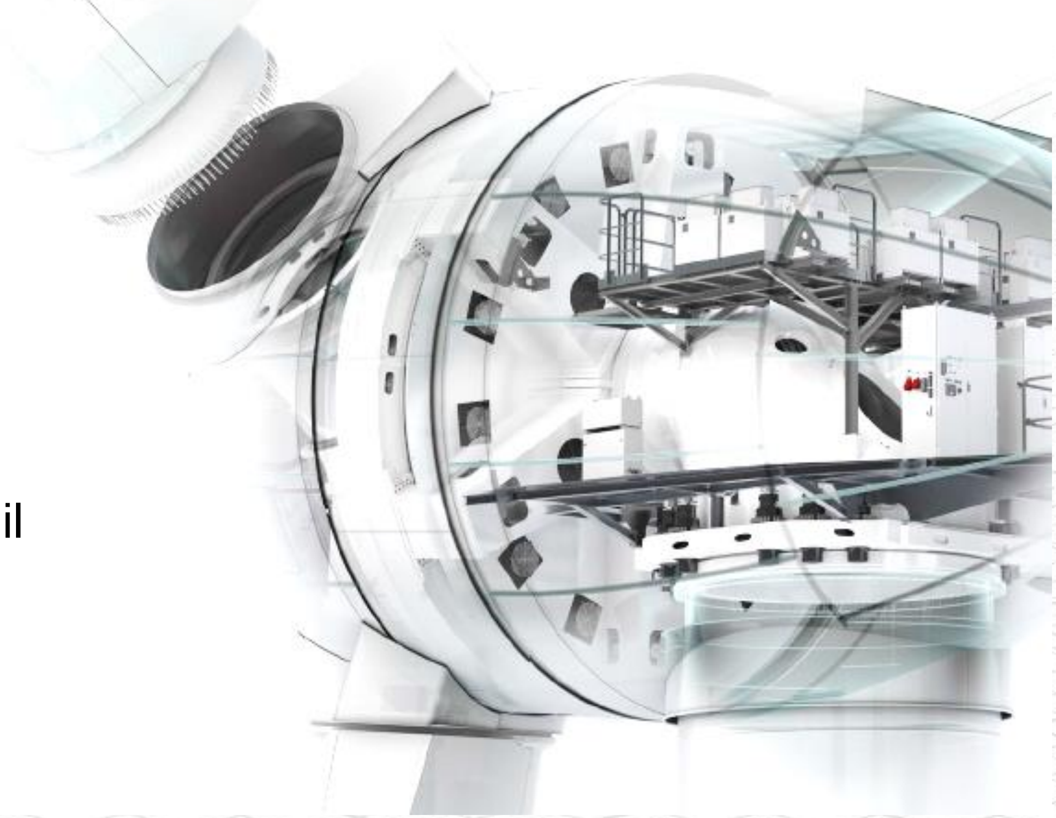
Full-Converter Wind Turbines:
Flexibility for grid code compliance of wind farms



Danilo Caldas

ENERCON Sales - Grid Integration
Latin America

30 August 2017 – Rio de Janeiro - Brazil

Agenda

- **Introduction**
- **Wobben Windpower and ENERCON**
- **ENERCON Electrical Concept**
- **Grid Requirements**
  - **Fault Ride Through**
  - **Voltage and Frequency Ranges**
  - **Reactive Power (PQ Diagram)**
  - **Voltage Control**
  - **Inertia Emulation**
  - **Harmonics**
- **Conclusion**

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Introduction

- Grid code:
  - Grid operator impose rules for new generation plants;
  - In Brazil: “Procedimentos de Rede”;
  - Standardization and System safety;
- Increase of wind energy penetration:
  - New grid operation;
  - New connection rules;
- Modern Wind Farms:
  - Power Electronics can improve the grid behaviour;
  - Allows WECs (wind turbines) to have flexible Active and Reactive Power control;
  - Fault Ride Through capability (FRT);
- ENERCON Experience
  - Power electronics since 1993 (full-converter);
  - Similar to FACTS equipment;

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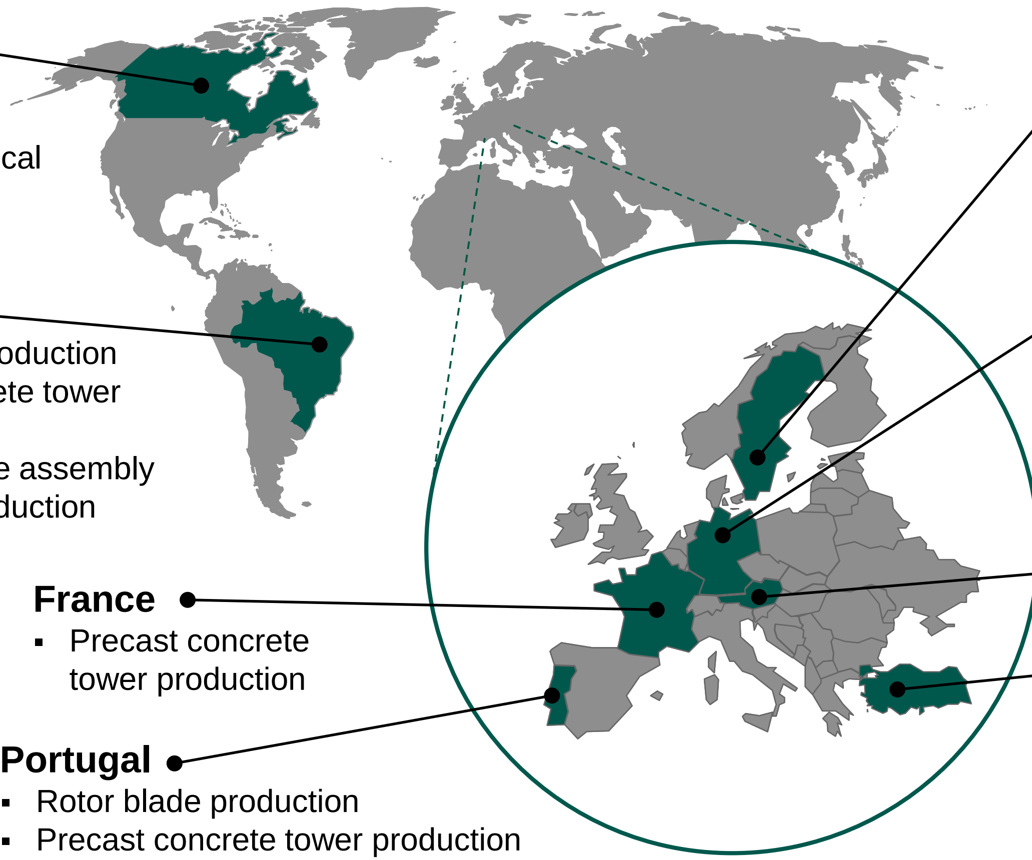
WORLDWIDE PRODUCTION IN EIGHT COUNTRIES



Canada
- Precast concrete tower production
- Production of electrical components

Brazil
- Rotor blade production
- Precast concrete tower production
- Machine house assembly
- Generator production

France
- Precast concrete tower production

Portugal
- Rotor blade production
- Precast concrete tower production
- Mechatronic
- Generator production

Sweden
- Steel tower production
- Metalworking

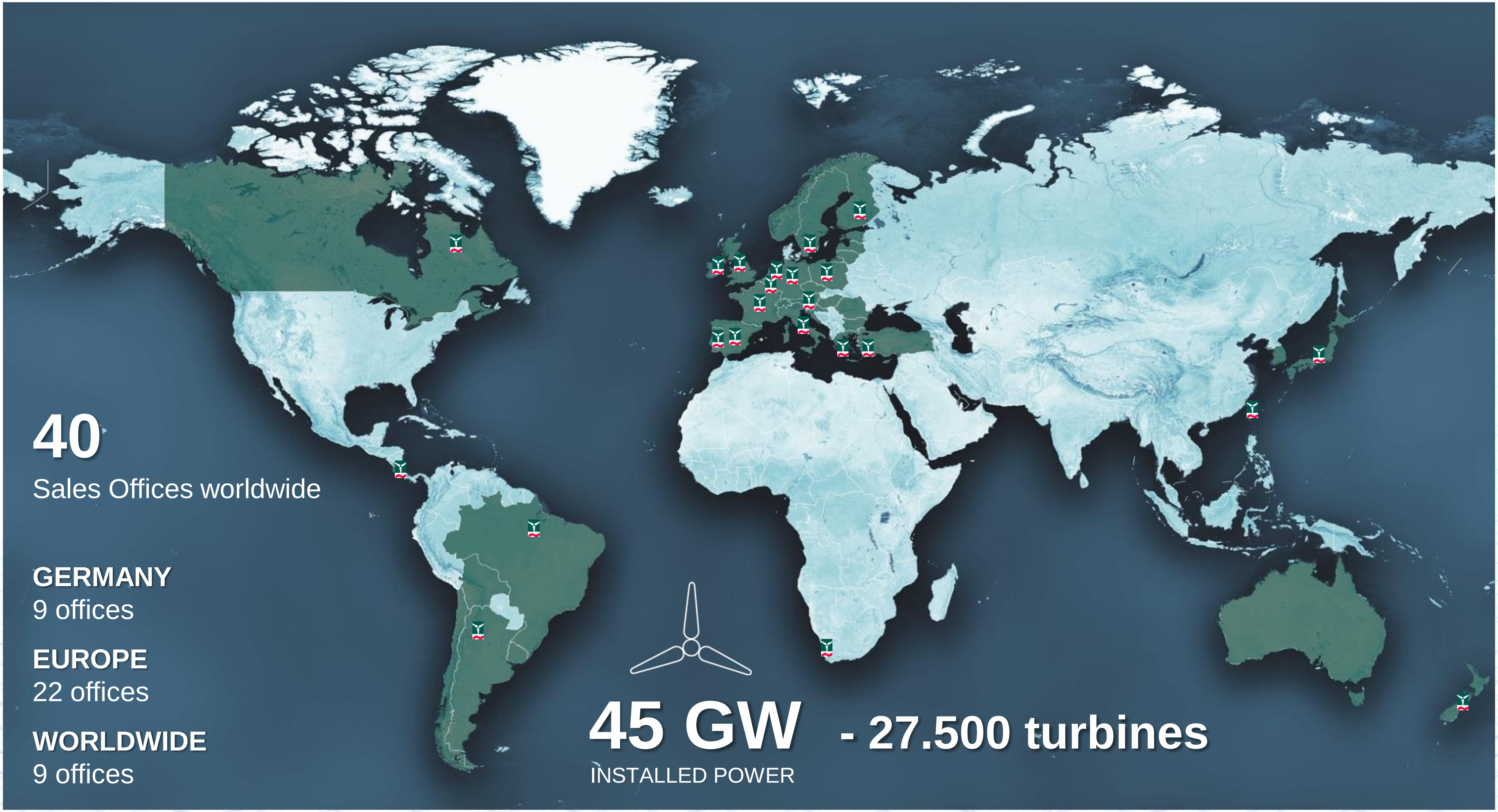
Germany
- Machine house assembly
- Electrical components
- Rotor blade production
- Generator production
- Tower production
- Foundry

Austria
- Precast concrete tower production

Turkey
- Rotor blade production
- Precast concrete tower production

ENERCON’s global production is characterised by a high degree of vertical integration

ENERCON World Presence



ENERCON no Brasil

- Wobben Windpower Industria e Comercio Ltda é uma empresa brasileira subsidiária da ENERCON GmbH

- A Wobben foi fundada em 1995 e teve um papel importante e pioneiro no Brasil:

  — Primeiro produtor independente de energia eólica no Brasil

  — Primeira empresa brasileira a produzir aerogeradores de grande porte no Brasil (800 a 2.350 kW)

  — Primeira empresa a instalar aerogeradores dentro do PROINFA

  — Primeira empresa a instalar aerogeradores de usinas eólicas contratadas no leilão de 2009

  — Possui usinas eólicas em operação no Brasil há 18 anos

A ENERCON NO BRASIL E AMÉRICA LATINA:

WOBBEN WINDPOWER

desde 1995 no Brasil

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WOBBEN WINDPOWER PRODUCTION FACILITIES IN BRAZIL

Rotor Blade
Pecém - CE

Concrete Tower
Juazeiro - BA

Generator, Nacele, Emodule and Blade
Sorocaba - SP

Steel Segment
Guaíba - RS

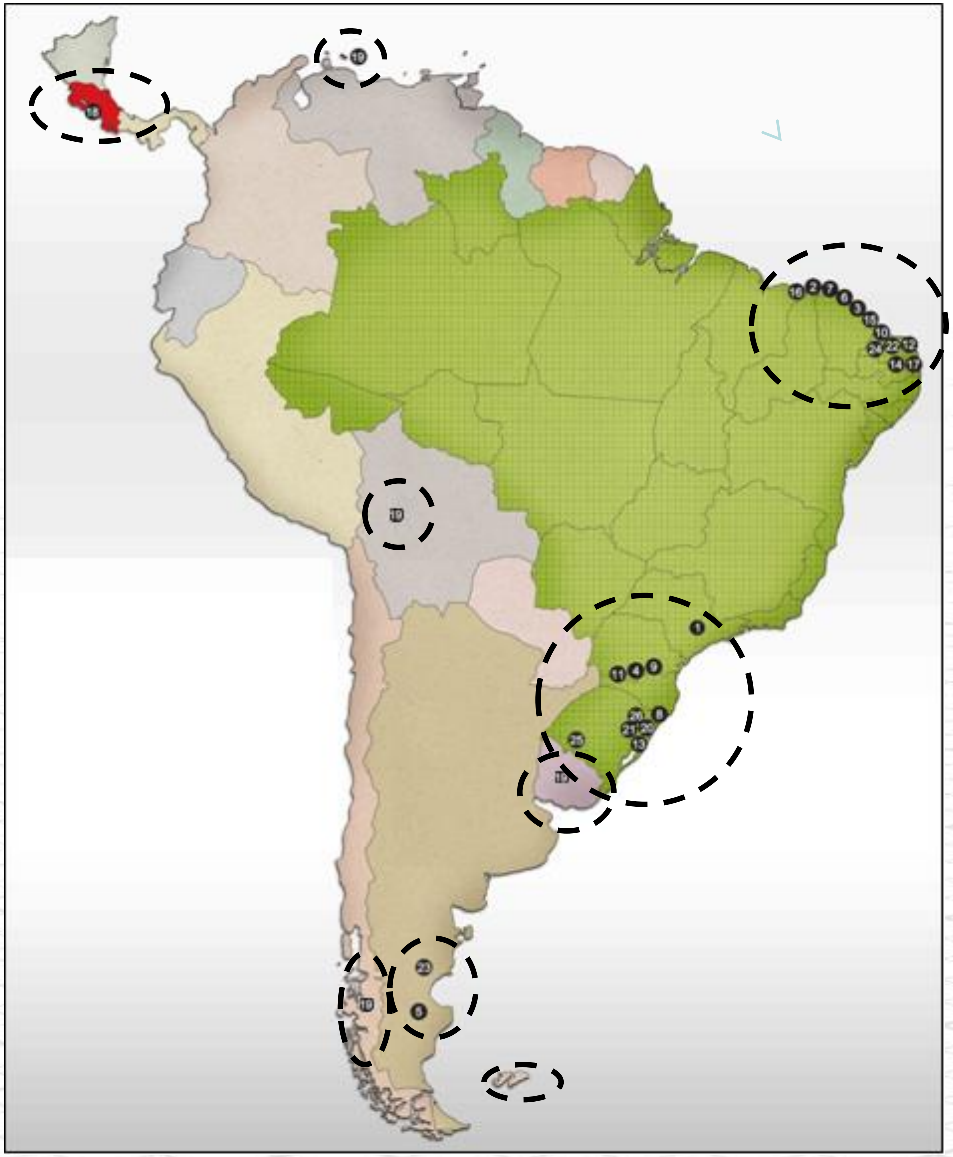
ENERCON Installation in Latin America

Antilhas Holandesas
11,13 MW

Costa Rica
64,8 MW

Ilhas Malvinas
2,97 MW

Brasil
1.198 MW
728 WECs



Argentina
8,7 MW

Uruguai
150 MW

Chile
1,8 MW

Bolivia
24 MW

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ENERCON Technology: History

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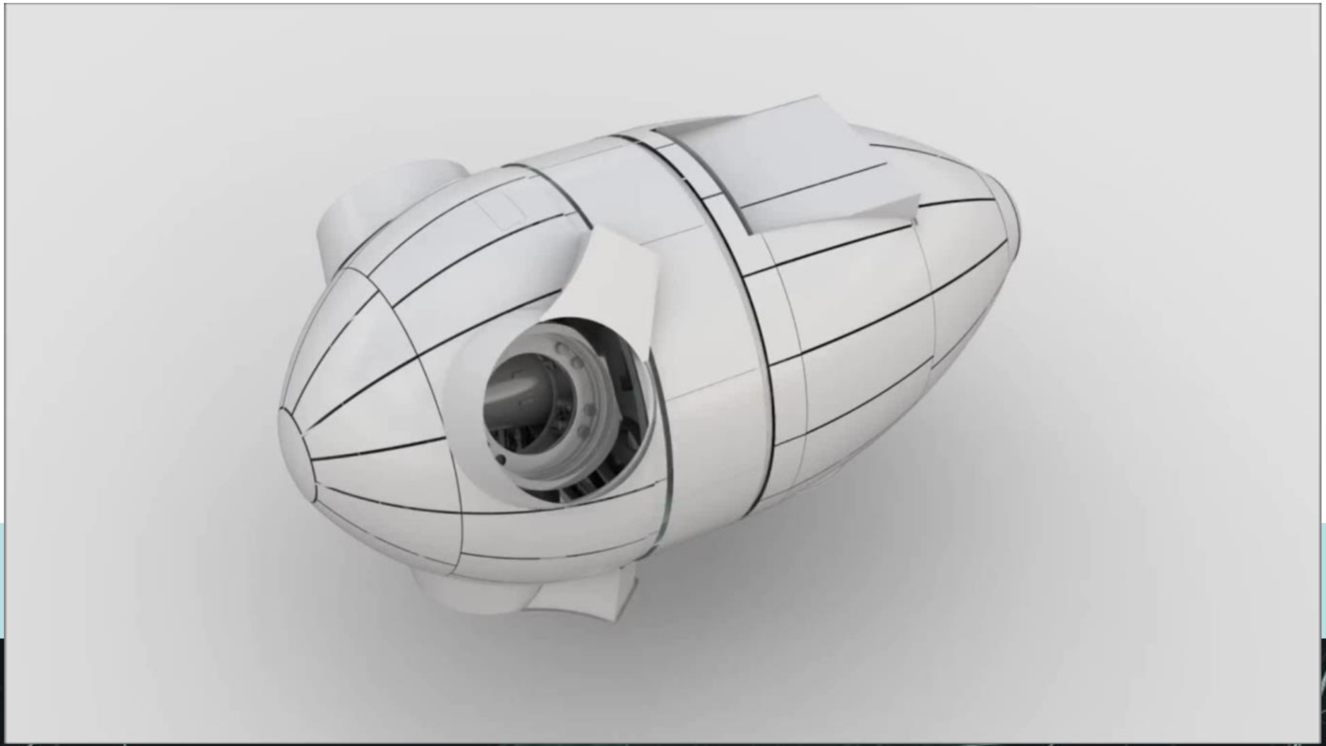
TIME-TESTED GEARLESS DRIVE TECHNOLOGY

- Little wear due to slow machine rotation
- Little mechanical stress due to high level of speed variability
- Yield-optimised control system
- High power quality



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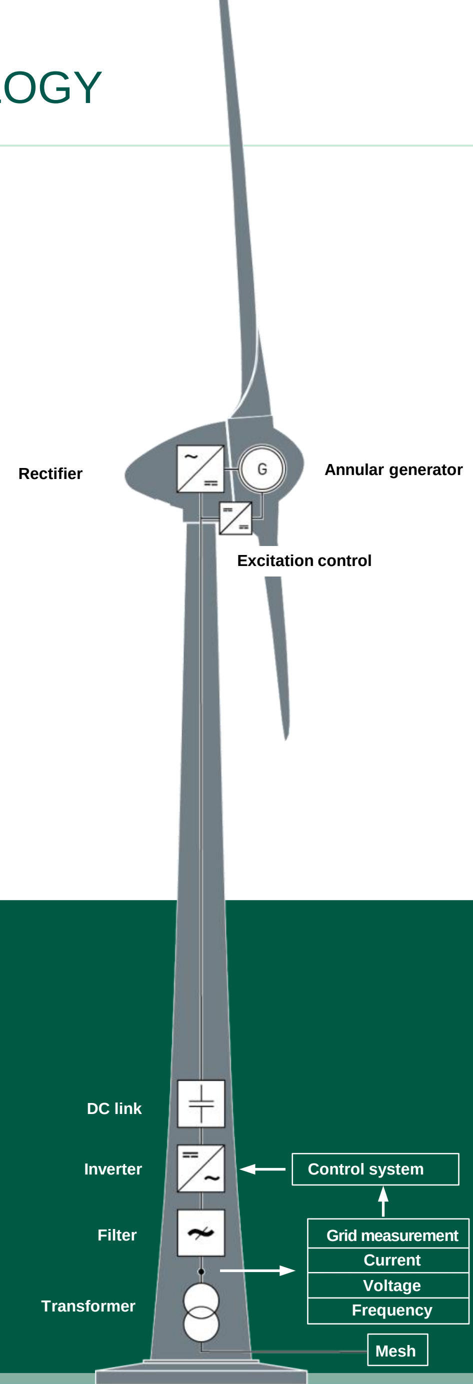
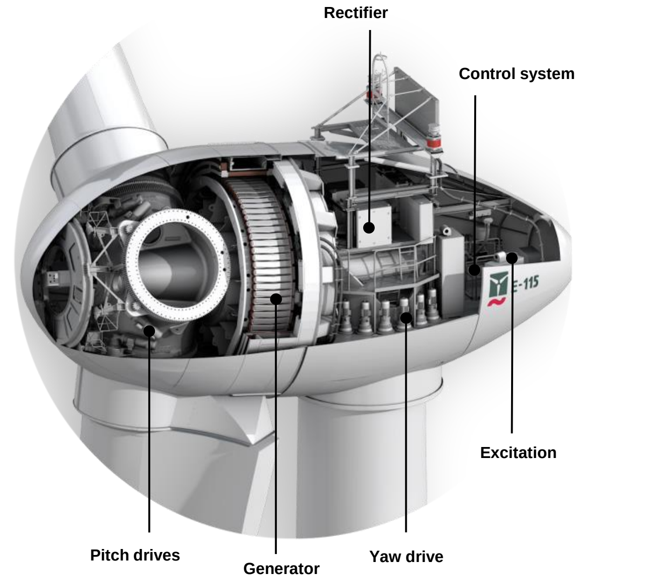
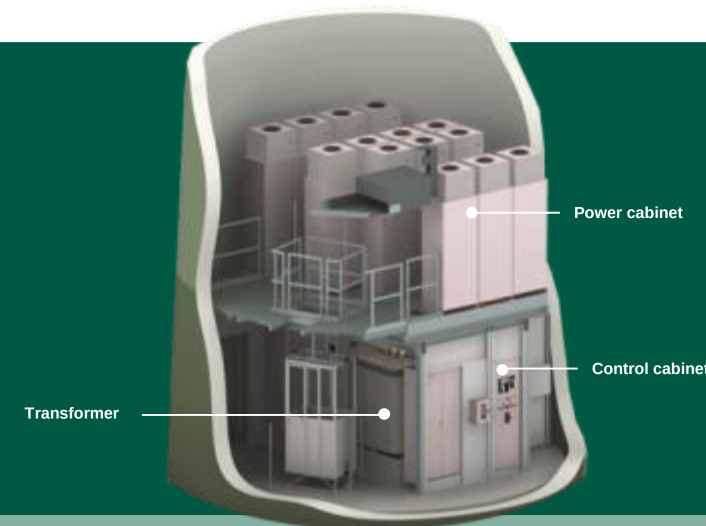
ELECTRICAL DESIGN

GENERATION





CONVERTION/TRANSFORMATION



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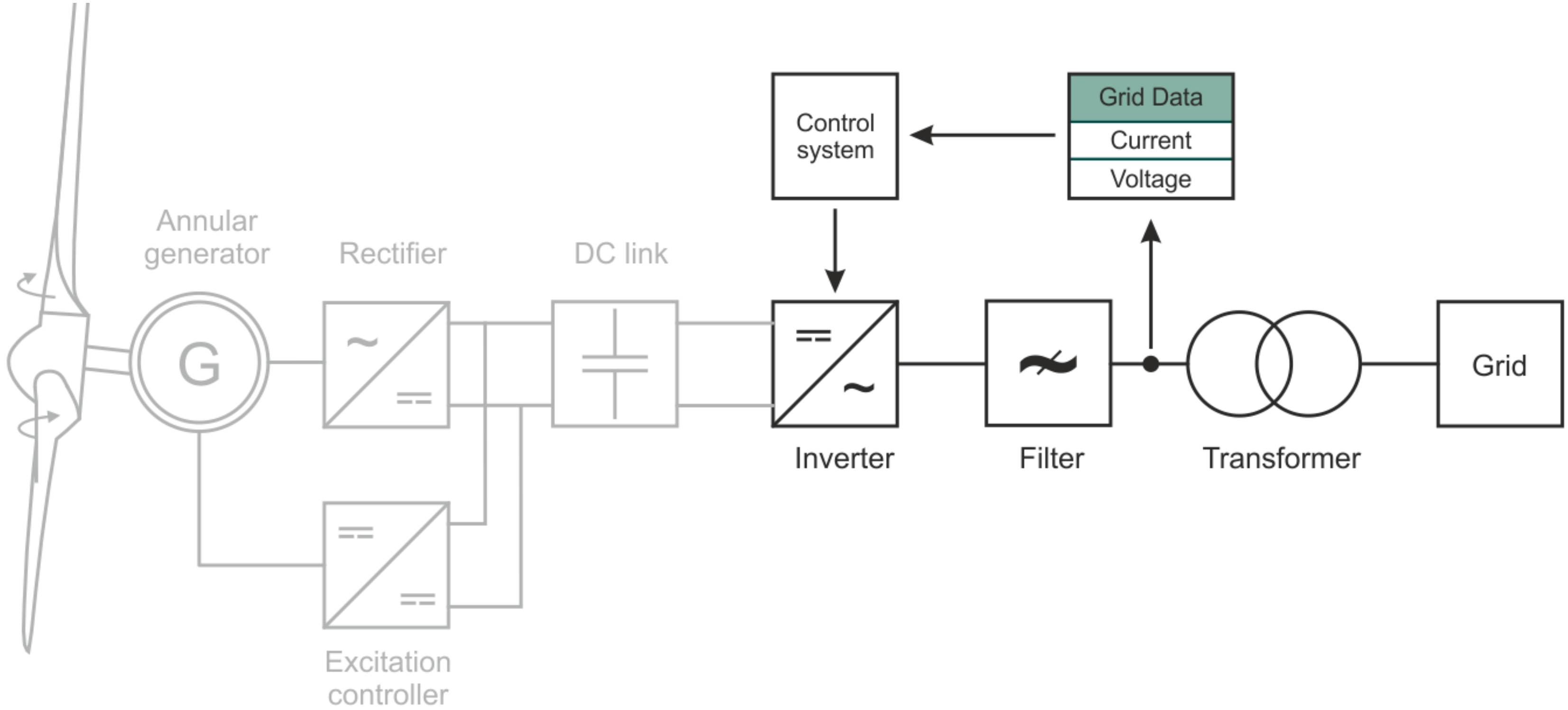
Key characteristics

- Wind Turbine Generator (WTG), with no gearbox
- Full scale power converters decouple the annular generator from the grid
- Available for 50Hz and 60Hz grids: no special version required
- Performance on grid mainly determined by inverter(s) (current source)



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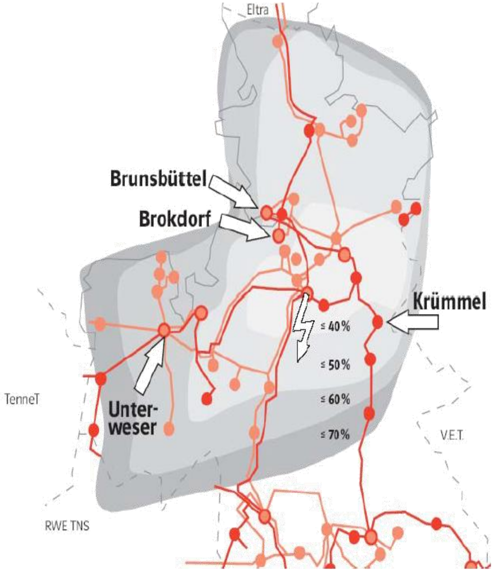
History of FRT requirement - Europe

- First wind farms in Europe:
  - Low influence in the grid
  - WEC disconnection during grid fault
- Higher penetration of renewables (wind and solar)
  - Disconnection of several generation units at the same time
  - Lack of generation: risk of frequency disturbances.
- Need of FRT



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History of FRT requirement - Brazil

Phase 1 (1992 – 2002): Pre-PROINFA

- No Grid Code for Wind – **22 MW**

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History of FRT requirement - Brazil

Phase 1 (1992 – 2002): Pre-PROINFA

- No Grid Code for Wind – **22 MW**

Phase 2 (2002 – 2010): PROINFA

- **2005:** No FRT requirement – **27,1 MW**
- **2007:** FRT for Under voltage – **245 MW**

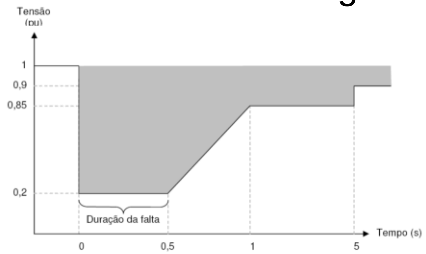

Figura 1 - Tensão nos terminais dos aerogeradores

- **2010:** **932,4 MW**

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History of FRT requirement - Brazil

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Phase 1 (1992 – 2002): Pre-PROINFA

- No Grid Code for Wind – **22 MW**

+5 MW

Phase 2 (2002 – 2010): PROINFA

- **2005:** No FRT requirement – **27,1 MW**
- **2007:** FRT for Under voltage – **245 MW**

+ 218 MW

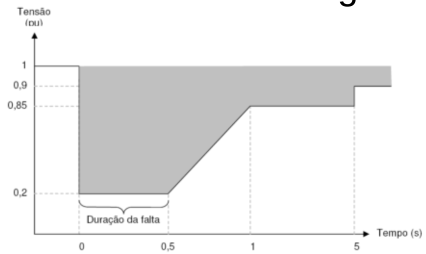


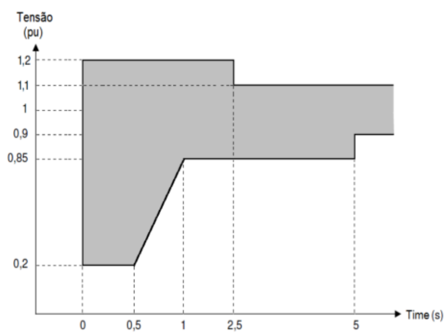
Figura 1 - Tensão nos terminais dos aerogeradores

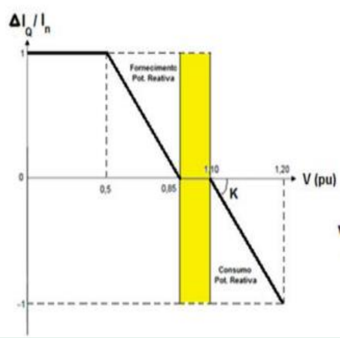
- **2010: 932,4 MW**

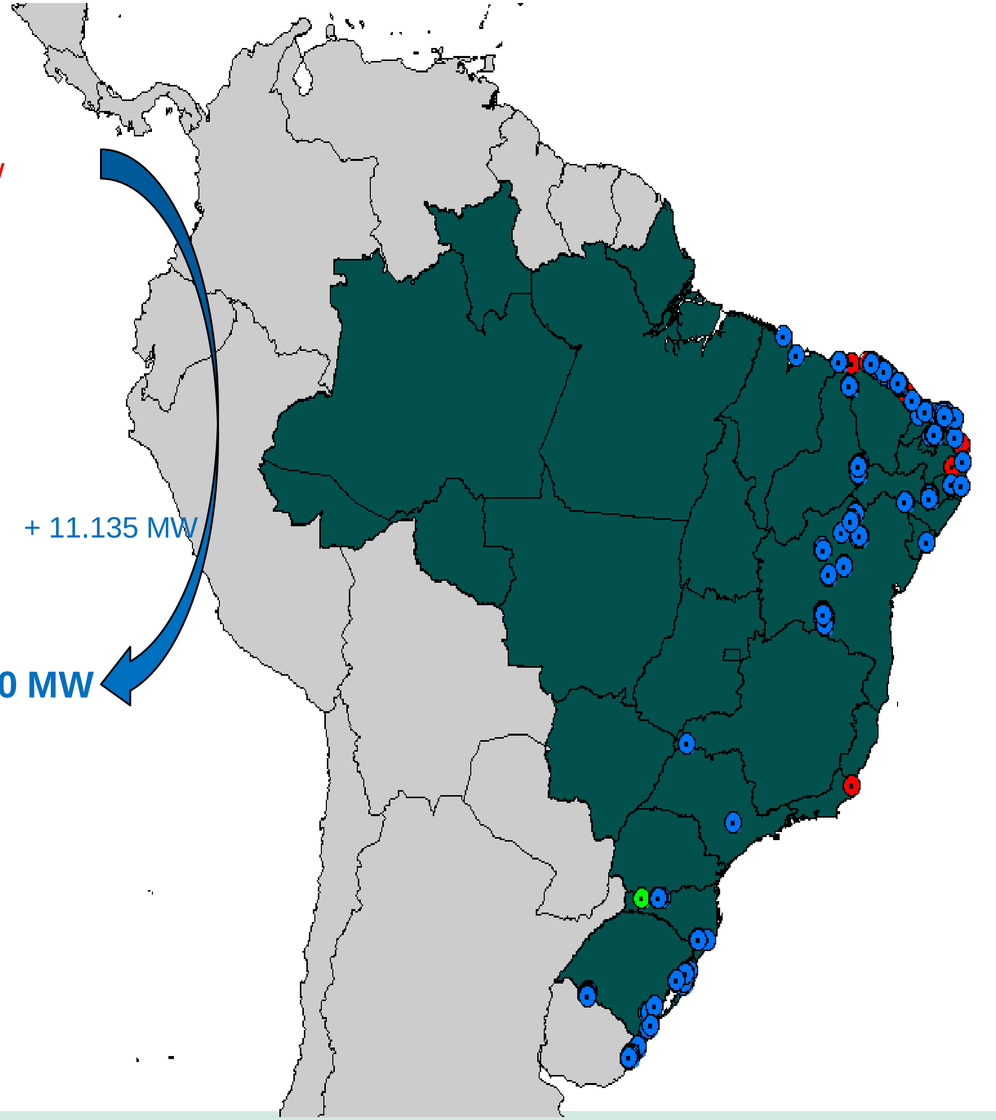
+ 11.135 MW

Phase 3 (2009 – Today): Auction and Free-Market

- **2017:** Reactive during fault and Overvoltages – **11.380 MW**







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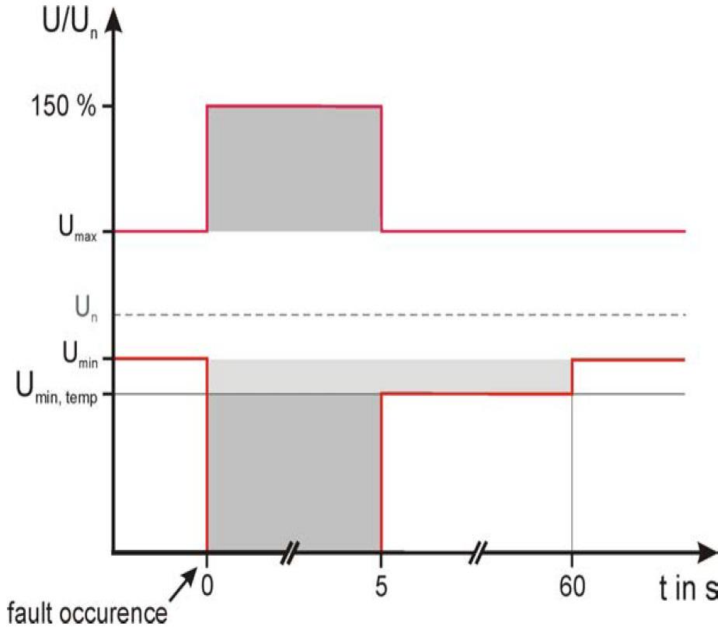
FRT in Full Converter WEC

FRT Capability

- FRT capability of an ENERCON WEC with regards to voltage and time.
- WEC can stay connected and provide fault currents during the dark grey shaded area.
- WECs operational for Un=0V up to 5seconds



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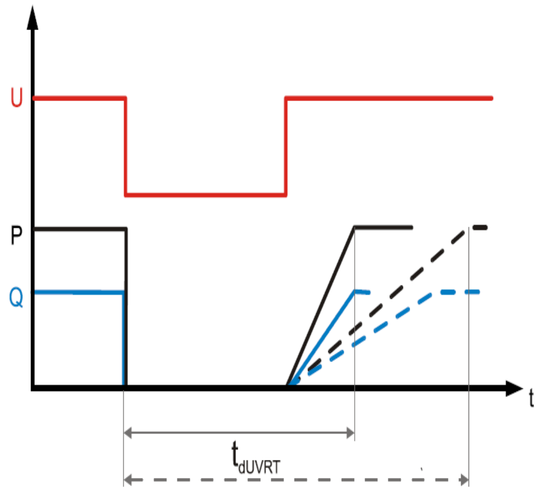
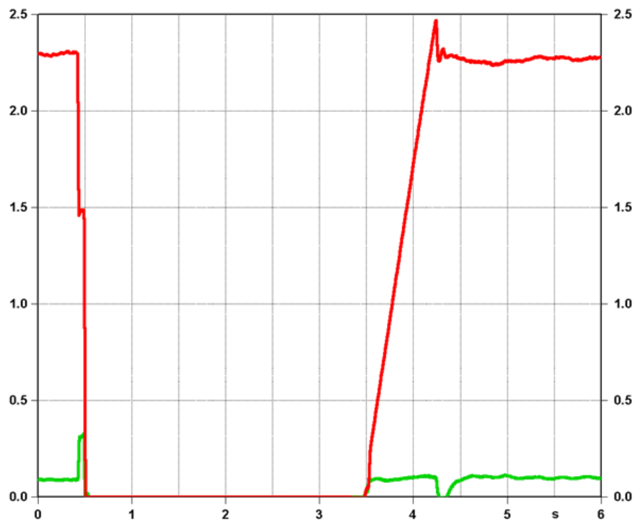
ZPM (Zero Power Mode)

- Available for symmetrical and asymmetrical faults.
- No current injection during fault.
- Generated power completely dissipated in choppers.
- Restart of current injection immediately or with settable ramp.
- WEC can be galvanically disconnected or stay connected during voltage dip.





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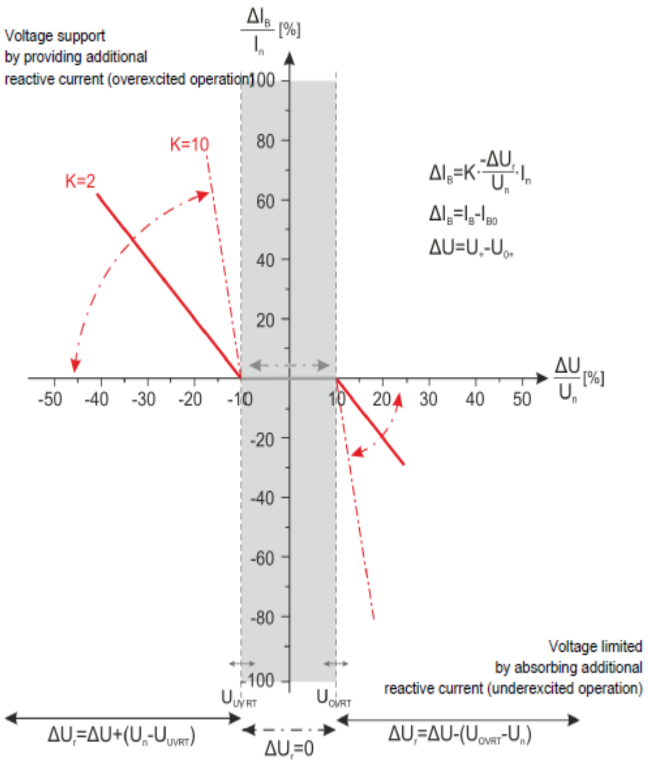
FRT in Full Converter WEC - Different FRT Modes

QU-Mode

- Available for symmetrical and asymmetrical faults.
- Provision of additional reactive current depending on voltage deviation.
- Active during
  - ➢ Under voltage conditions.
  - ➢ Over voltage conditions.
- Proportional K-factor can be adjusted project specifically:
  - ➢ Weak grids, low K.
  - ➢ Strong grids, high K.



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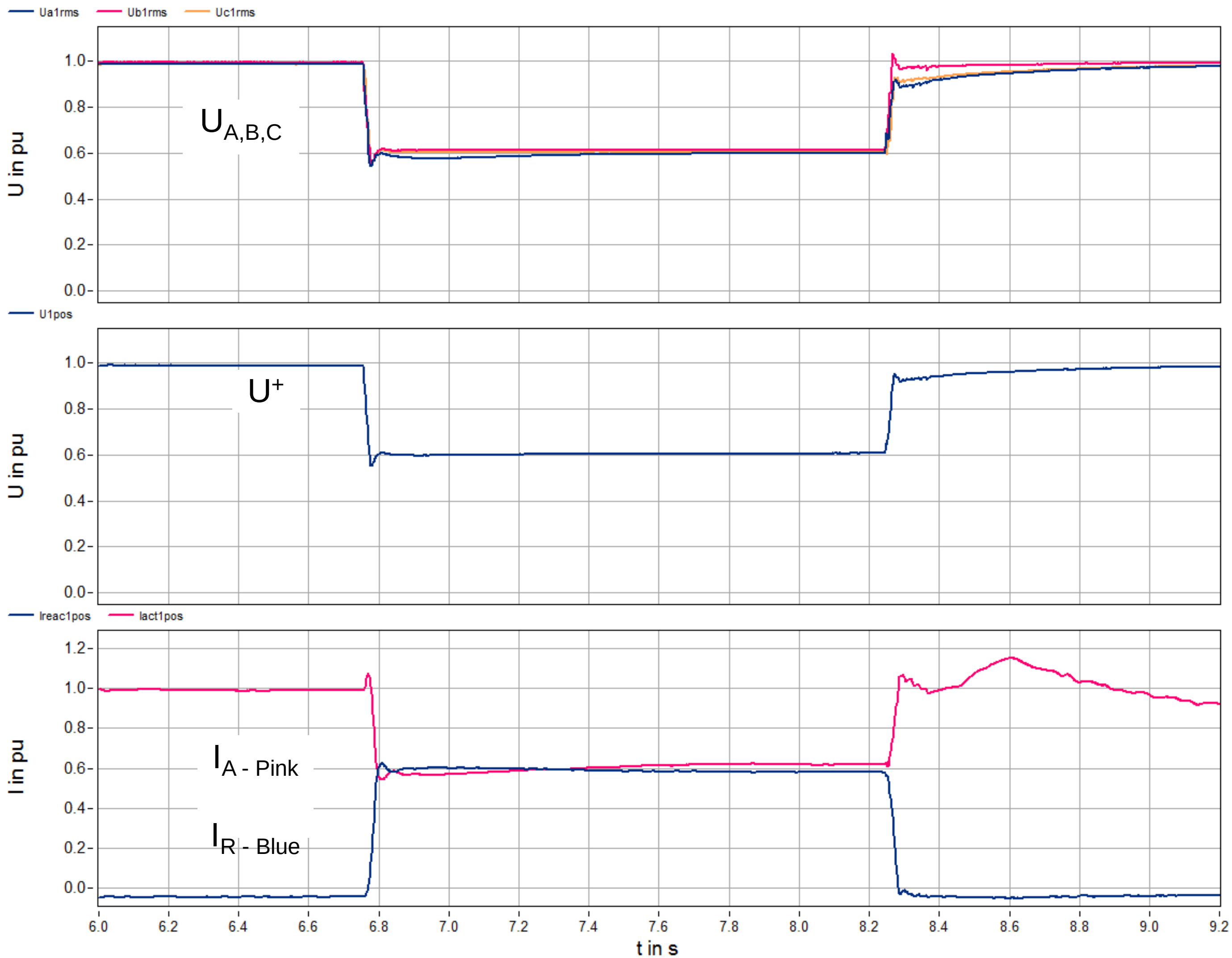
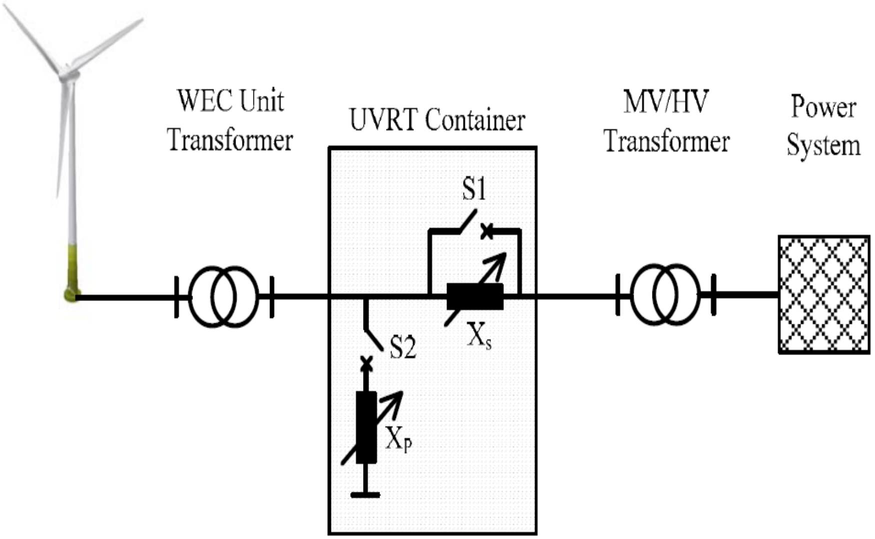
QU Mode 2 for balanced voltage dips



IEC 61400-21

- UVRT Tests
- Next Revision also OVRT



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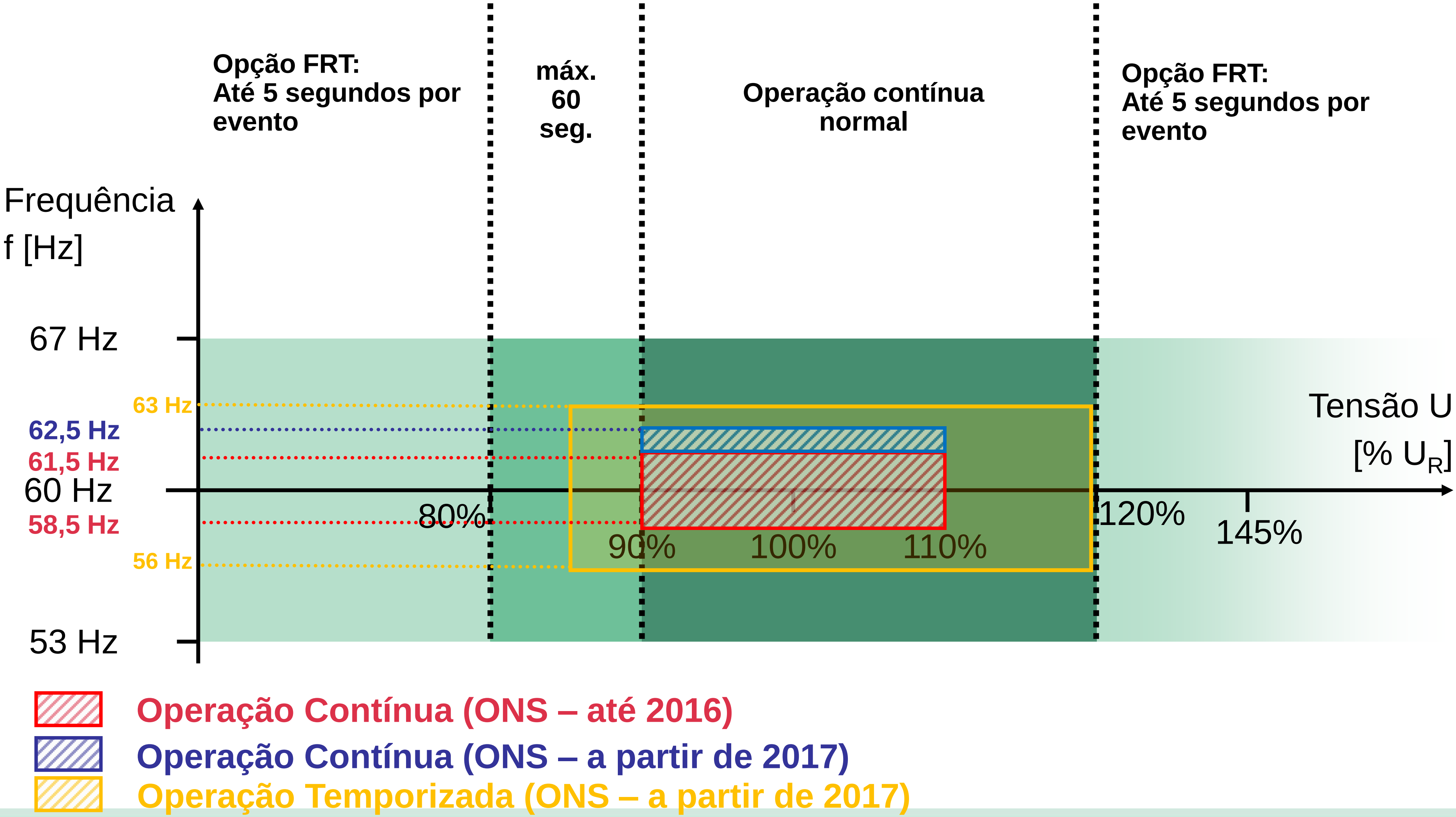
Limites de Tensão e Frequência:



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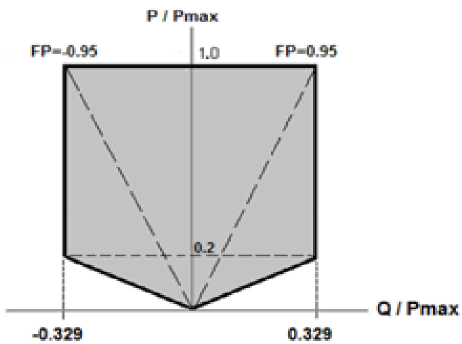
Submodulo 3.6 (2017)

“Na conexão de suas instalações de uso restrito às instalações sob responsabilidade de transmissora, a central de geração eólica deve propiciar os recursos necessários para operar com fator de potência indutivo ou capacitivo em qualquer ponto da área indicada na figura abaixo.



Nas condições em que os aerogeradores não estejam produzindo Potência Ativa, a central de geração eólica deverá ter recursos de controle para disponibilizar ao SIN sua capacidade de geração/absorção de potência reativa, observando o requisito mínimo de propiciar injeção/absorção nula no ponto de conexão, como indicado na figura acima.”

ONS Operador Nacional do Sistema Elétrico

Submódulo 3.6

Requisitos técnicos mínimos para a conexão às instalações de transmissão

Rev. Nº.	Motivo da revisão	Data e instrumento de aprovação pela ANEEL
1.1	Atendimento à Resolução Normativa ANEEL nº 312/08, de 06 de maio de 2008.	15/09/2010 Despacho SRT/ANEEL nº 2744/10
2016.12	Versão decorrente de Audiência Pública nº 020/2015	16/12/16 Resolução Normativa nº 756/16

Resumo:

- Maior exigência de potencia Reativa (Diagrama PQ Pentagonal)
- Q=0 para P=0 – Compensação de cabos no Ponto de Conexão.

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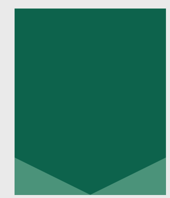
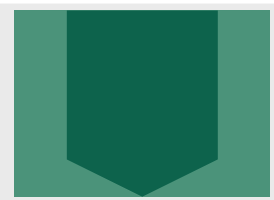
Capacidade de Potência Reativa

Available electrical configurations

Configuration	Meaning	Corresponding PQ diagram
FT	**F = F**ACTS capabilities **T = T**ransmission = FRT option	
FTQ	**F = F**ACTS capabilities **T = T**ransmission = FRT option **Q = Q**+ option	
FTS	**F = F**ACTS capabilities **T = T**ransmission = FRT option **S = S**TATCOM option	
FTQS	**F = F**ACTS capabilities **T = T**ransmission = FRT option **Q = Q**+ option **S = S**TATCOM option	

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Submodulo 3.6 (2017)

A central geradora deve ser capaz de operar em 3 modos distintos de operação:

- controle de tensão,
- controle de potência reativa, e
- controle de fator de potência.

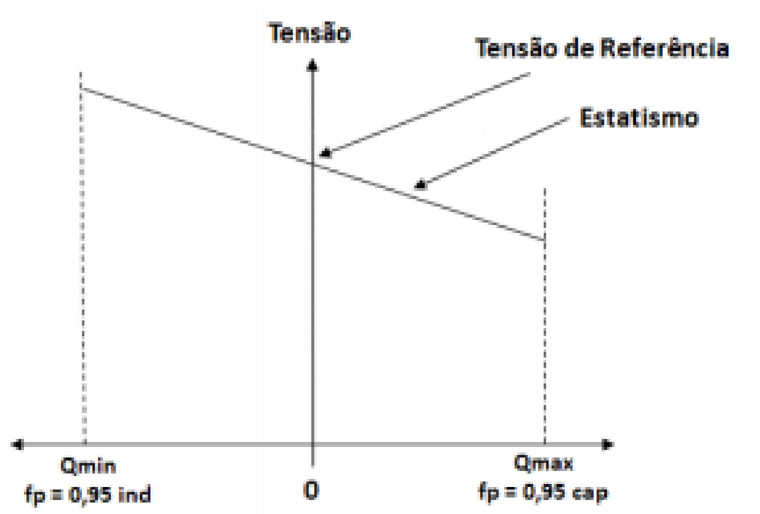

Figura 3 – Perfil do Controle de Tensão da central geradora eólica.

ONS Operador Nacional do Sistema Elétrico

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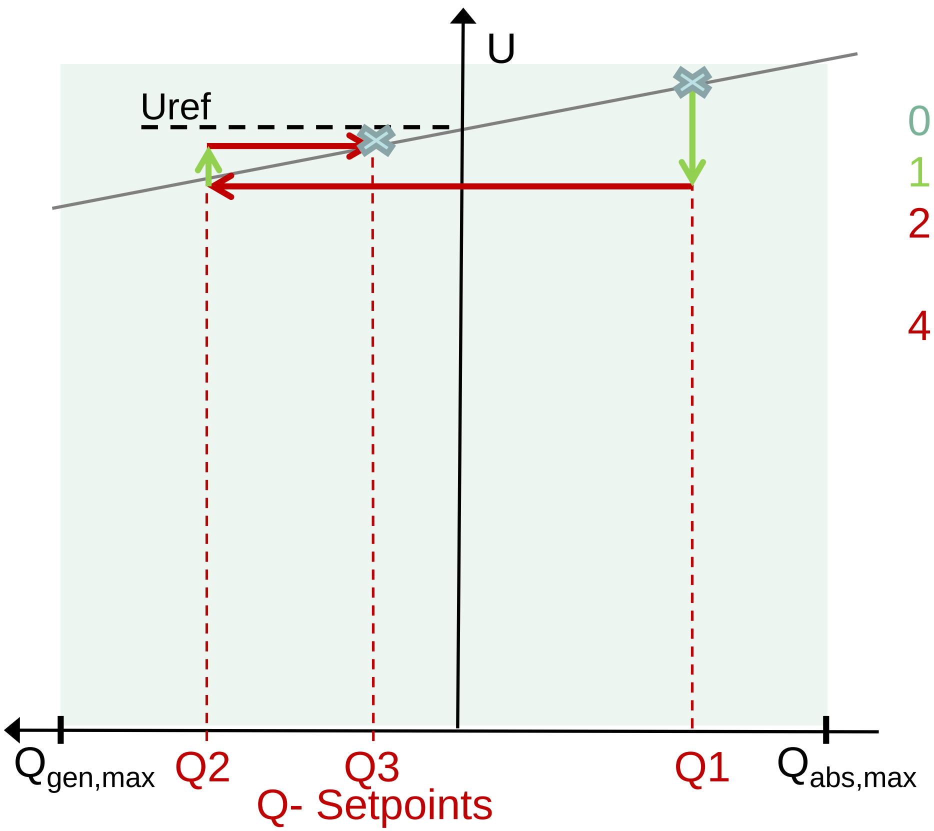
Voltage droop control (Q/U)

- Wind farm controls reactive power output to value resulting from linear Q/U slope (usually defined by system operator)
- Slope can be shifted by changing reference voltage (more options for FCU)



0. Initial steady state operating point
1. Grid voltage decreases
2. Wind Farm adapts Q output
   =>Changed Q output changes voltage
4. Wind Farm adapts Q again until steady state operating point is reached …

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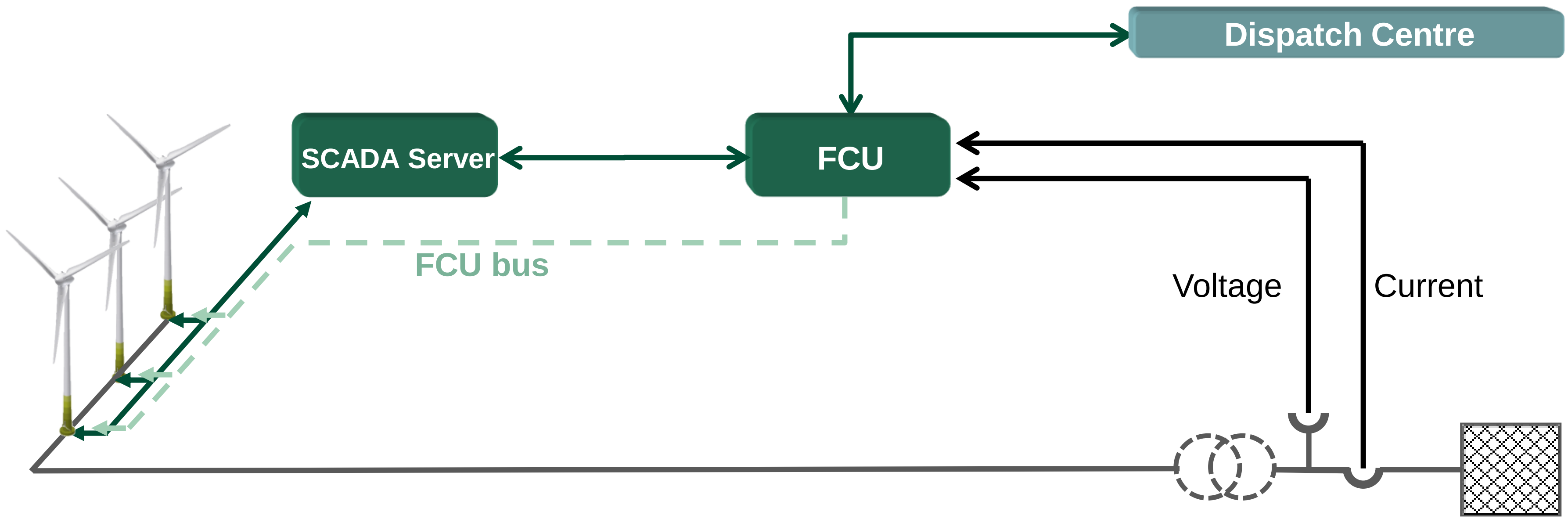
ENERCON Farm Control Unit (FCU)

Key characteristics

- Advanced, flexible controller for wind farms
- Can be very fast due to dedicated data bus for set points to WECs
- High dynamic performance with rise times as low as 1s
- Project specific simulations and on-site compliance testing (fine-tuning) required



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Inertia Emulation: International Experience

ENCERCON ENERGY FOR THE WORLD

Canada (Hydro Quebec and IESO)

- Wind Farms > 10 MW
- Increase of P for 5% of Pn for 10 s in response to severe frequency dips (Quebec)
- Increase of P for 10% of Pactual (pre-disturbance) for 10 s (Ontario)

Ireland (Eirgrid)

- Synthetic Inertia (called Fast Frequency response) is not a minimal requirement
- It will be part of a package of ancillary services package (DS3 System Services)
- From 2 – 8 seconds after under frequency the amount of extra P have to be more than the P in the recovery period (10-20 seconds after the event)

European Union (ENTSO-E)

- The TSO have the right to request for Synthetic Inertia during fast frequency deviations

Brazil (ONS)

- Annex IX from Auction rules and in the "Procedimentos de Rede" from 2017.
- Wind Farms have to contribute with 10% of its nominal power during events of under frequencies

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Synthetic Inertia

- Os aerogeradores de centrais com potência instalada **superior a 10 MW** deverão dispor de controladores sensíveis às **variações de frequência**, de modo a **emular a inércia** (inércia sintética) através de modulação transitória da potência de saída, contribuindo com **pelo menos 10% de sua potência nominal**, por um período mínimo de **5 segundos**, quando em regime de subfrequência, para **desvios de frequência superiores a 0,2 Hz**.
- A **retirada** desta contribuição deverá ser **automaticamente** efetuada caso a frequência retorne a seu **valor nominal.**
- A **injeção inicial** de potência ativa deverá ser **proporcional à variação da frequência**, a uma **taxa mínima de 0,8 pu** da potência nominal do aerogerador para **cada hertz** de desvio da frequência.
- A **provisão plena** de inércia sintética deverá ser disponibilizada sempre que a potência ativa do aerogerador for **igual ou superior a 25% de sua potência nominal**.
- Deverão ser informados os **tempos máximos de sustentação do adicional de potência de 10%** para níveis de potência **inferiores a 25% da potência nominal** do aerogerador.


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Submódulo 3.6

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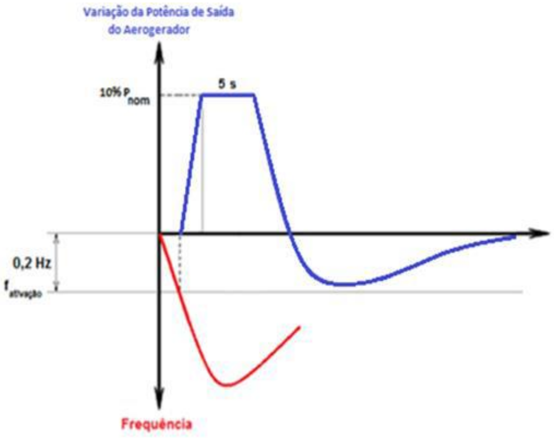

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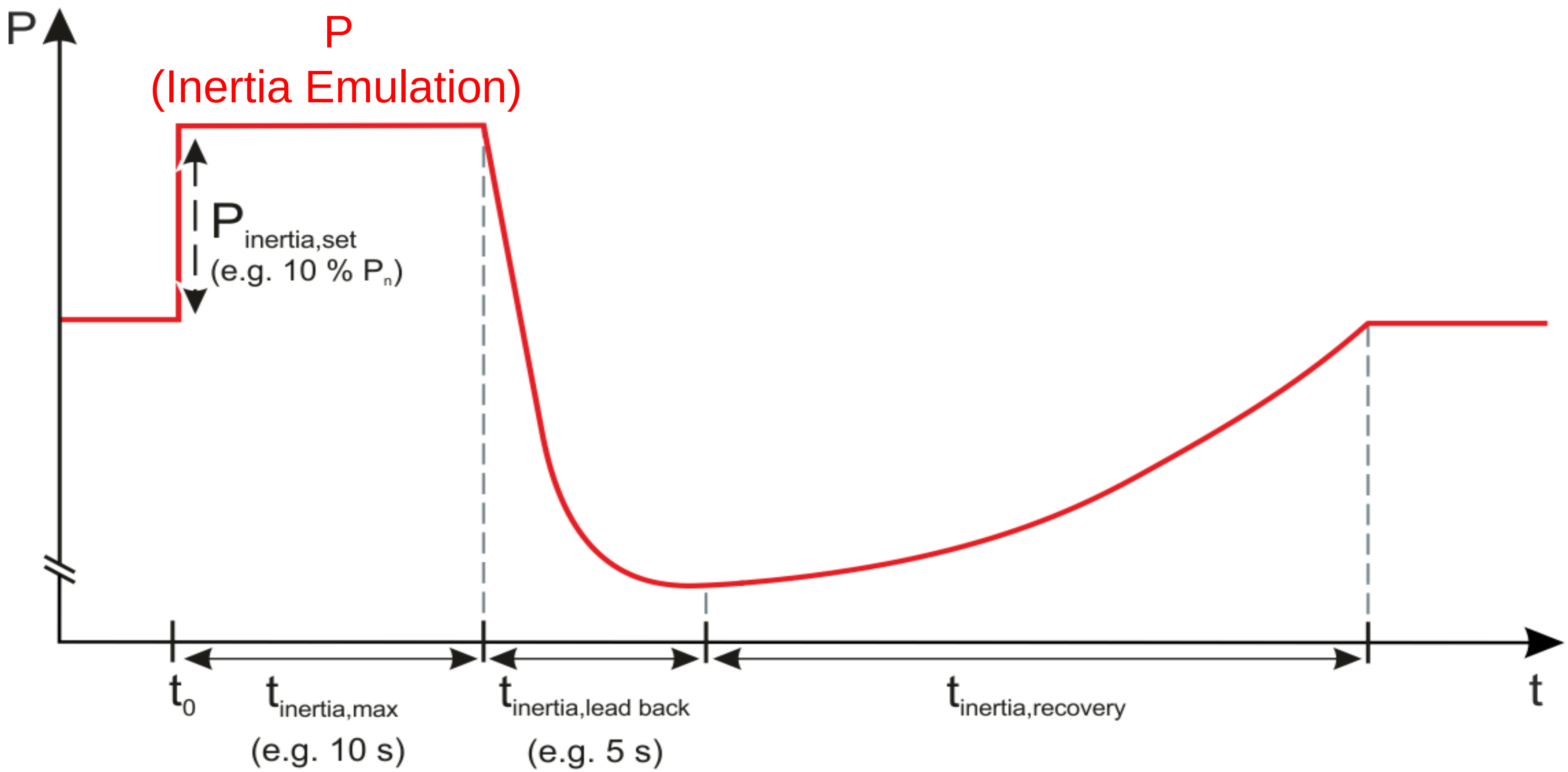
Inertia Emulation: ENERCON Concept



ENERCON Inertia Emulation experience since 2008
More than 1GW of wind turbines installed.

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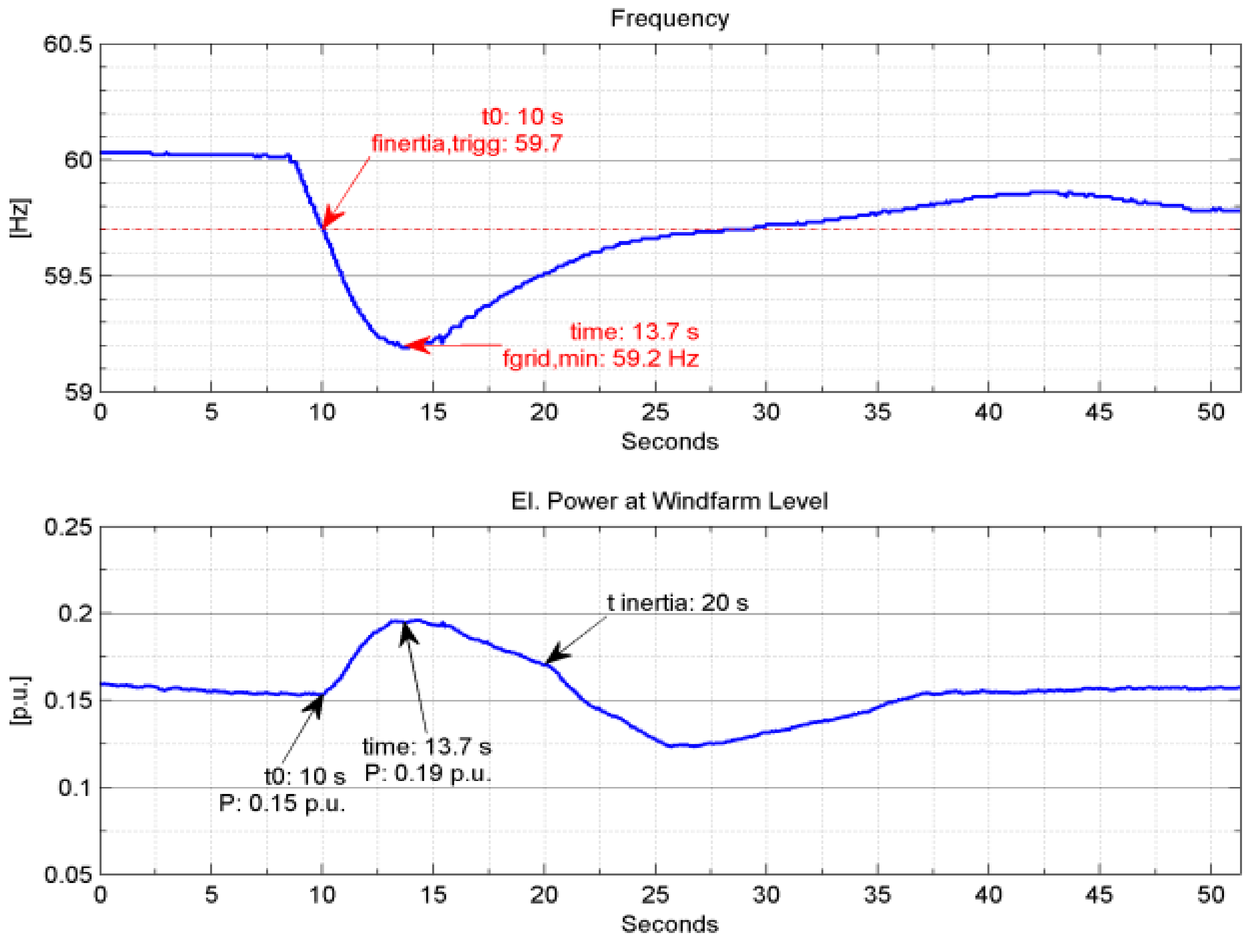
Inertia Emulation: Real Measurement Results

Wind Farm Data



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Brazilian Power Quality Limits

- Limits to be respected at the Point of Connection.

Tabela 4-1: Limites individuais de distorção harmônica

13,8 kV ≤ V < 69 kV				V ≥ 69 kV			
ÍMPARES		PARES		ÍMPARES		PARES	
ORDEM	VALOR(%)	ORDEM	VALOR(%)	ORDEM	VALOR(%)	ORDEM	VALOR(%)
3 a 25	1,5			3 a 25	0,6		
		todos	0,6			todos	0,3
≥27	0,7			≥27	0,4		
DTHTS95% = 3				DTHTS95% = 1,5			

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Brazilian Power Quality Study

1 WEC = IEC extract or measured

$\sum$ Wind farm current

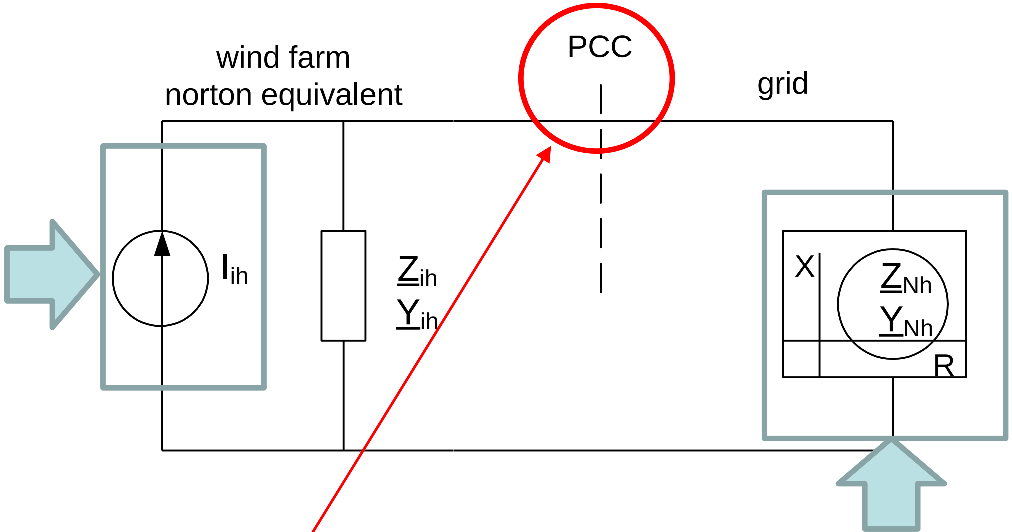
$$I_{n,total} = \left(\sum_{i=1}^{m} I_{n,i}^{a} \right)^{(1/a)}$$

Onde,

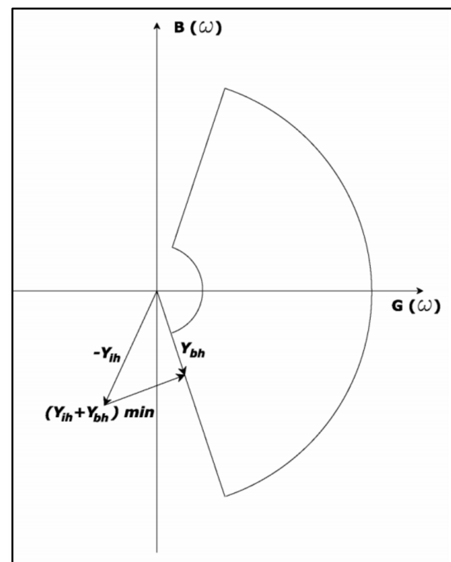
n - ordem harmônica

m – número total de fontes

a	Ordem da harmônica
1	n < 5
1,4	5 ≤ n ≤ 10
2	n > 10



Calculated Vh at the PoC shall be below the ONS limits. If not filters shall be installed



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ENERCON ENERGY FOR THE WORLD

Measurement

- All ENERCON WECs are measured by independent institutes according to IEC 61400-21
- Reference point is low voltage terminals of unit transformer
- Extract of test reports available, showing
  - Harmonics
  - Interharmonics
  - Voltage fluctuations
  - Flicker
- ENERCON actively involved in drafting of IEC 61400-21 Ed. 3

WINDTEST
A GL company

Laboratory accredited by DAP Deutsches Akkreditierungssystem Prüfwesen GmbH according to DIN EN ISO/IEC 17025. This accreditation is valid for the test and measurement procedures given in the certificate.

DAP Deutscher Akkreditierungs Rat
DPT-PL-1556.01

Extract from the test report „Measurement and assessment of power quality characteristics of the wind turbine of the type ENERCON E-82 E2 according to parts of the IEC 61400-21 Edition 2.0 (August 2008)"	WT 8029/10 Page 1/3

Type:	ENERCON E-82 E2	Manufacturer's specification:	
Configuration:	"F"	Generic type of installation:	pitch, full converter
Manufacturer:	ENERCON GmbH Dreekamp 5 26605 Aurich	Rated frequency:	50 Hz
		Rated power P_n:	2300 kW
		Rated wind speed v_n:	12 m/s
		Rated apparent power S_n:	2300 kVA
Test report:	WT 8028/10	Rated current I_n:	3320 A
Period of measurement:	2010-03-16 to 2010-04-23	Rated voltage U_n:	400 V
Order no. (WINDTEST):	4280 09 06426 252	Reactive power set-point control:	Q = 0

Maximum measured power

P_{600} [kW]	2338.7	P_{60} [kW]	2353.5	$P_{0.2}$ [kW]	2436.1
$p_{600} = P_{600} / P_n$	1.02	$p_{60} = P_{60} / P_n$	1.02	$p_{0.2} = P_{0.2} / P_n$	1.06

Voltage fluctuations

Network impedance phase angle, ψ_k [°]	30°	50°	70°	85°
Annual average wind speed, v_a [m/s]	Flicker coefficient, $c(\psi_k, v_a)$			
v_a = 6.0 m/s	3.41	2.69	1.77	1.23
v_a = 7.5 m/s	3.45	2.74	1.80	1.26
v_a = 8.5 m/s	3.47	2.74	1.80	1.26
v_a = 10.0 m/s	3.48	2.75	1.81	1.27

Switching operations

Case of switching operation	Start-up at cut-in wind speed			
Max. number of switching operations, N_{10}	3			
Max. number of switching operations, N_{120}	35			
Network impedance phase angle, ψ_k [degrees]	30	50	70	85
Flicker step factor, $k_f(\psi_k)$	0.02	0.02	0.01	0.01
Voltage change factor, $k_u(\psi_k)$	0.09	0.07	0.04	0.02

Case of switching operation	Start-up at rated wind speed or higher			
Max. number of switching operations, N_{10}	3			
Max. number of switching operations, N_{120}	35			
Network impedance phase angle, ψ_k [degrees]	30	50	70	85
Flicker step factor, $k_f(\psi_k)$	0.08	0.06	0.05	0.04
Voltage change factor, $k_u(\psi_k)$	0.89	0.67	0.38	0.16

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What is coming: IEC 61400-21 Ed.3

"Due to the fact, that harmonic emission measurements at wind turbines are often influenced by **background noise** and are often **dependent on the grid impedances** (resonances in the grid), a new informative annex (Annex D: Harmonic evaluation) was included in the IEC61400-21. This annex gives further methods for analysis of harmonic measurements, like for harmonic voltages and harmonic phase angles. In addition this annex also gives guidance, how to recognize or how to minimize the influence of background noise."

- Annex D: Harmonic Evaluation (Future)
  - Daily variation from the harmonic measured
  - Disconnect Loads and Generators around the Wind Farms
  - Harmonic Current vs Active Power
  - Internal Filters (Measurements with and without)
  - WEC harmonic measured isolated system
  - Harmonic direction (phase angle measurement)
  - Harmonic Voltage with and without the WEC

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Agenda

- Introduction
- Wobben Windpower and ENERCON
- ENERCON Electrical Concept
- Grid Requirements
  - Fault Ride Through
  - Voltage and Frequency Ranges
  - Reactive Power (PQ Diagram)
  - Voltage Control
  - Inertia Emulation
  - Harmonics
- **Conclusion**

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Conclusions

- ONS is following the example of most developed countries in terms of wind energy integration.
- Some technical details shall be arranged Project specifically (UVRT, Voltage Control, Inertia, etc...).
- Technical discussion in terms of grid Integration shall be done in the planning phase (Electrical Studies, Definition of Internal Grid Topology, Discussions with ONS).

- New Challenges:
  - ➢Voltage Control,
  - ➢Synthetic Inertia
  - ➢Harmonics

- Future:
  - ➢Storage for primary control
  - ➢Negative Sequence Injection during fault
  - ➢Remuneration for Reactive Power

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ENERCON
ENERGY FOR THE WORLD
Ø: 126m
h: 135m
Pn: 7580 kW
Year: 2015
Ø: 25m
h: 30m
Pn: 300 kW
Year: 1987

Wobben/ENERCON in the BWP 2017:

Day	Participant	Time	Subject
29/08/2017	Marcos Madureira	14h00	**Workshop:** Project Management como interface única na Construção de Parques Eólicos
30/08/2017	Danilo Caldas	10h00	**Workshop:** Aerogeradores Full-Converter : Flexibilidade para o cumprimento de códigos de rede em parques eólicos
30/08/2017	João Paulo Cavalcanti	14h00 - 16h00	**Plenária O&M:** Manutenção de Parques Eólicos - Visão Fabricantes e Investidores
31/08/2017	Fernando Real	11h00	**Plenária BWP:** Desafios do SUPPLY CHAIN

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BWP 2017 - booth 101-106

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