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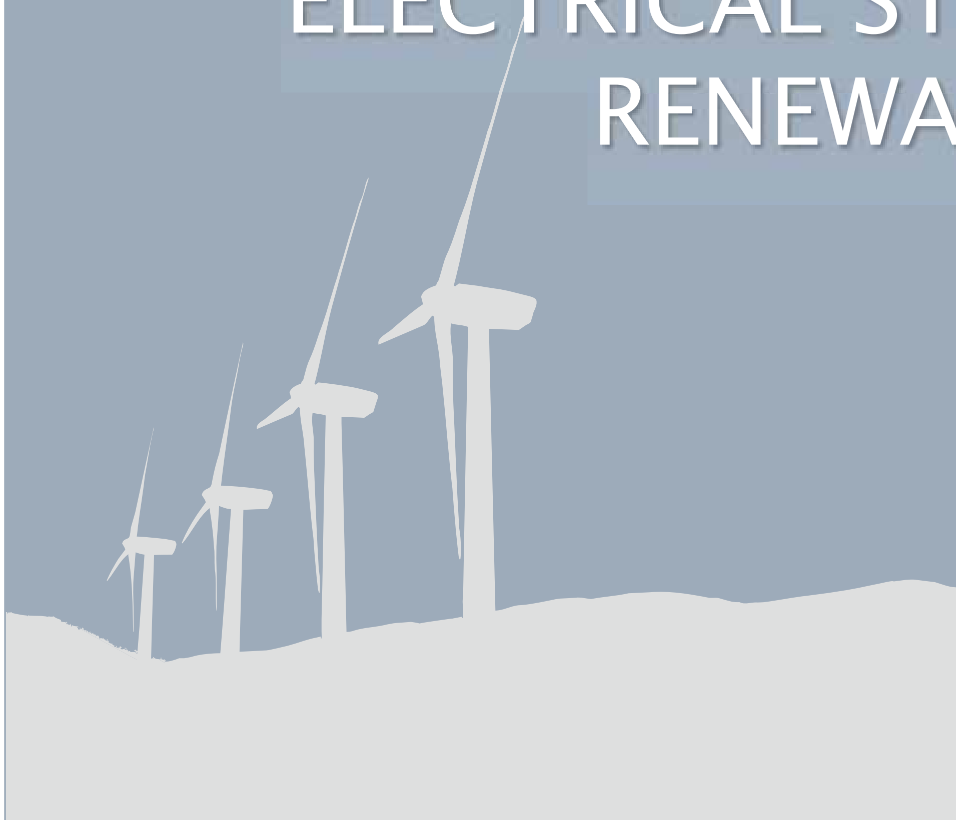
ELECTRICAL STUDIES OF VARIABLE RENEWABLE POWER PLANTS

PhD. Carlos Álvarez

Energy to Quality
Barlovento Group



World Bank, Washington DC
April 12^{th}, 2016

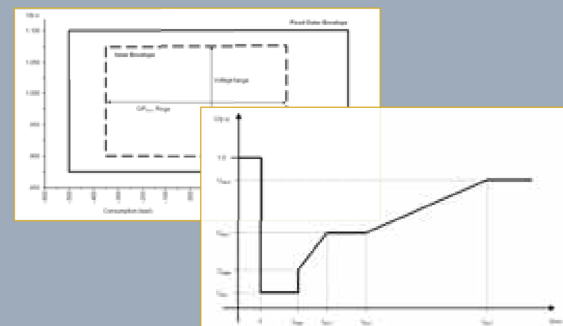
www.barloventorecursos.com

AGENDA

1. Introduction

2. Electrical Studies

3. Experiences in weak grids



4. Development of Guidelines / Grid Codes

5. Conclusions & Future Work

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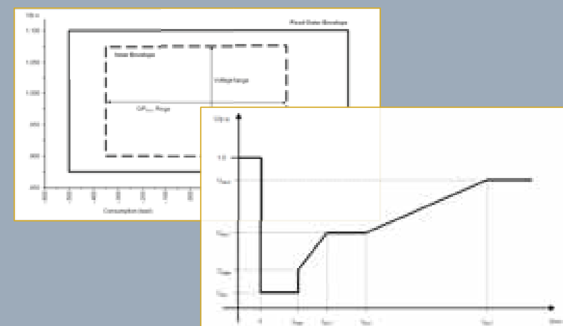

4. Development of Guidelines / Grid Codes

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WHO ARE WE?

- Barlovento group
- Energy to Quality
  - Origin
    - Accredited **LVRT Tests**
  - Current activities
    - Electrical consultant
    - Studies for grid code compliance
    - Model validation
    - Electrical laboratory
    - MEASNET membership

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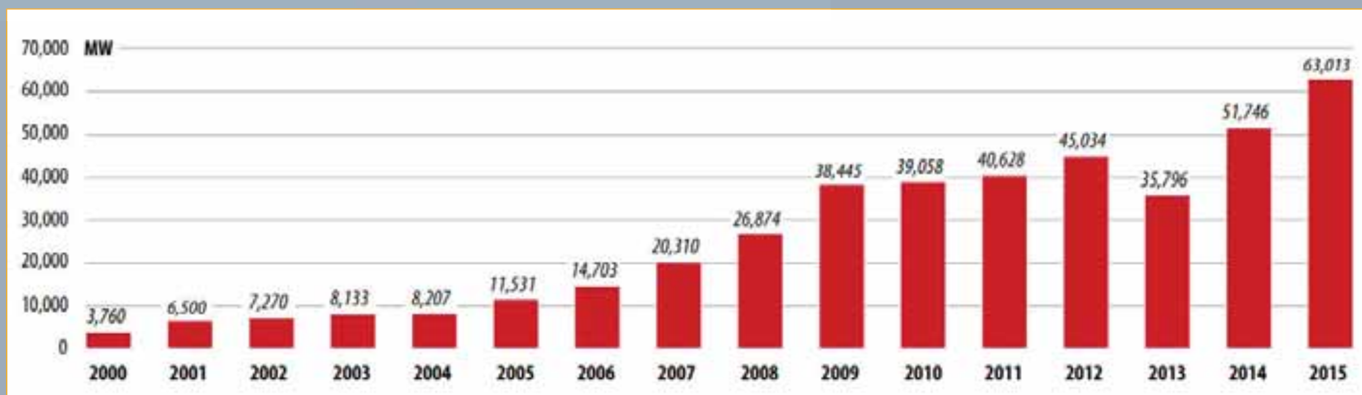
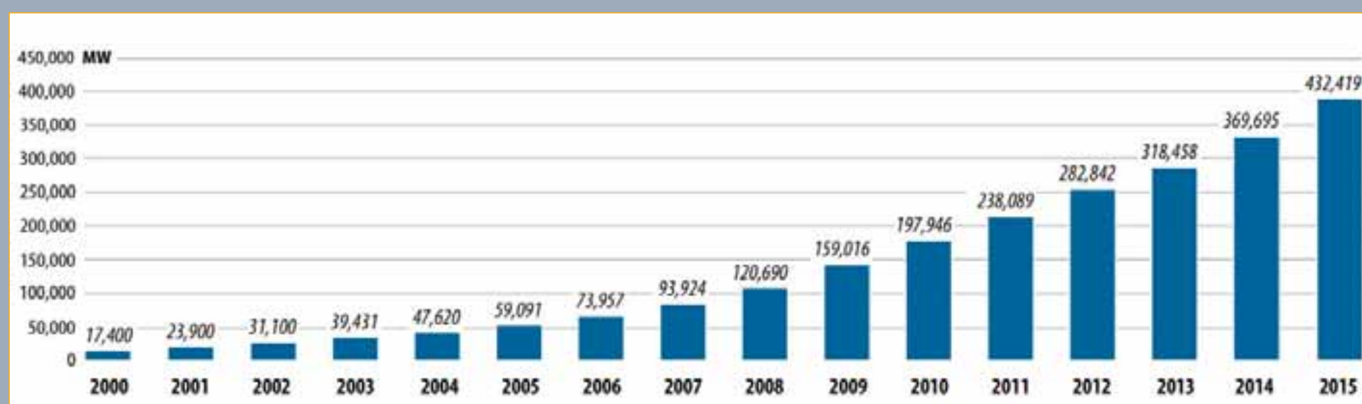
Some figures, wind



Wind power installed in the world, 2000-2015

Accumulated wind power installed in the world, 2000-2015



Data from GWEC

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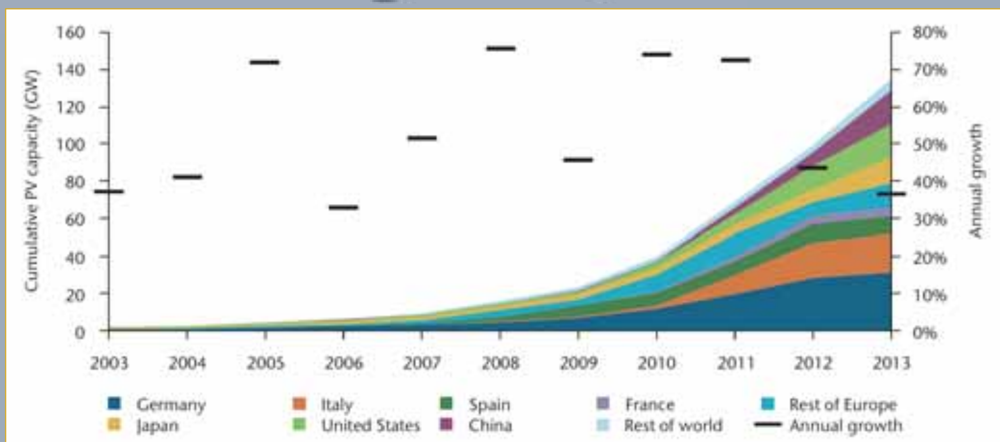
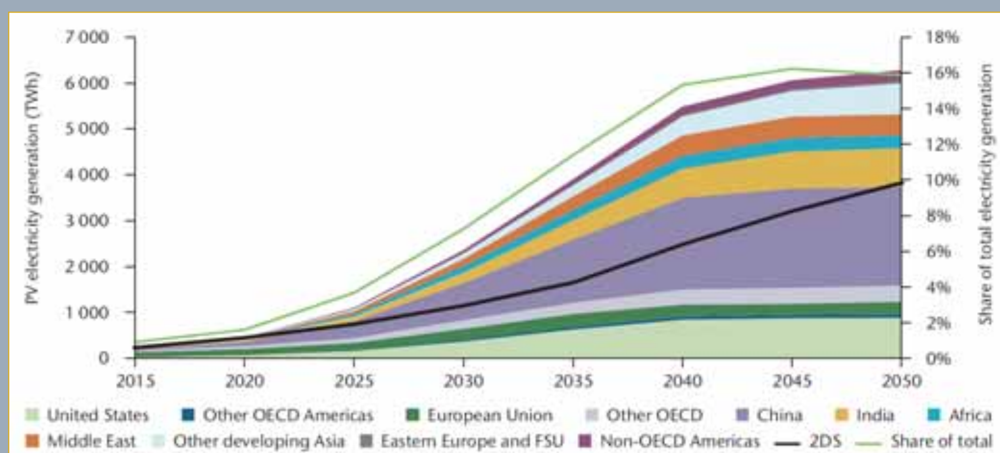
Some figures, PV



Global cumulative growth of PV capacity



Regional production of PV electricity envisioned in the 2014 IEA Roadmap

Data from IEA

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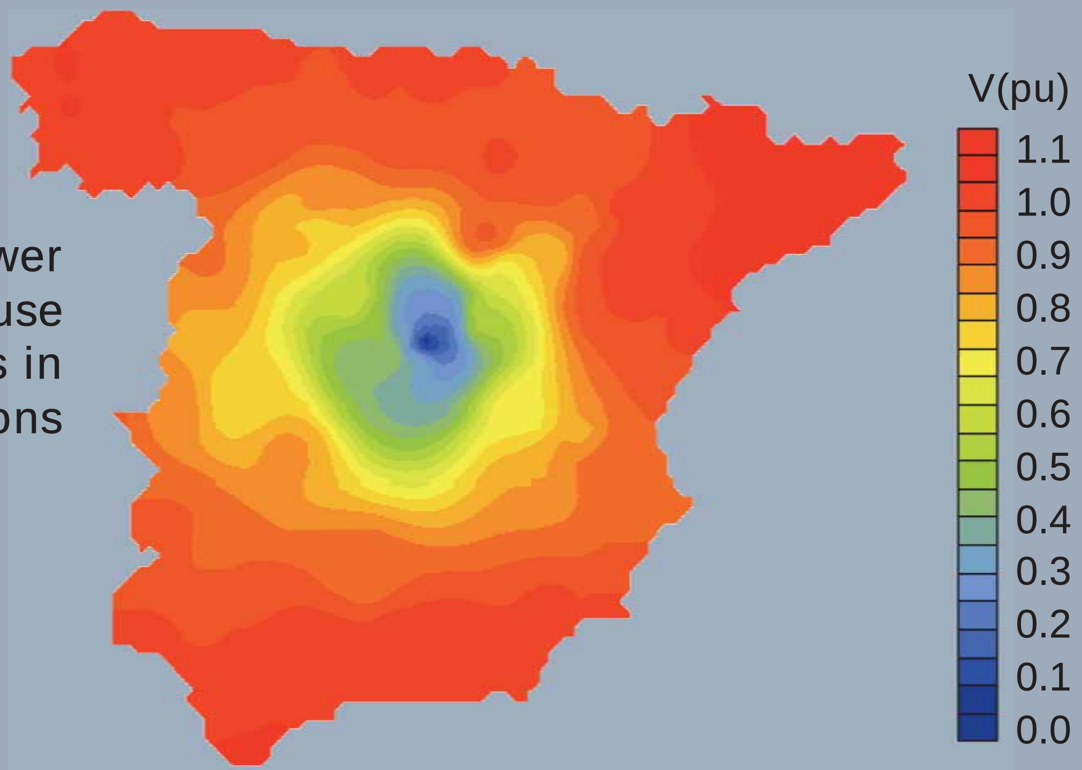
- Traditional problems, losses of energy due to voltage dips

Faults in the power system can cause voltage dips in remote locations



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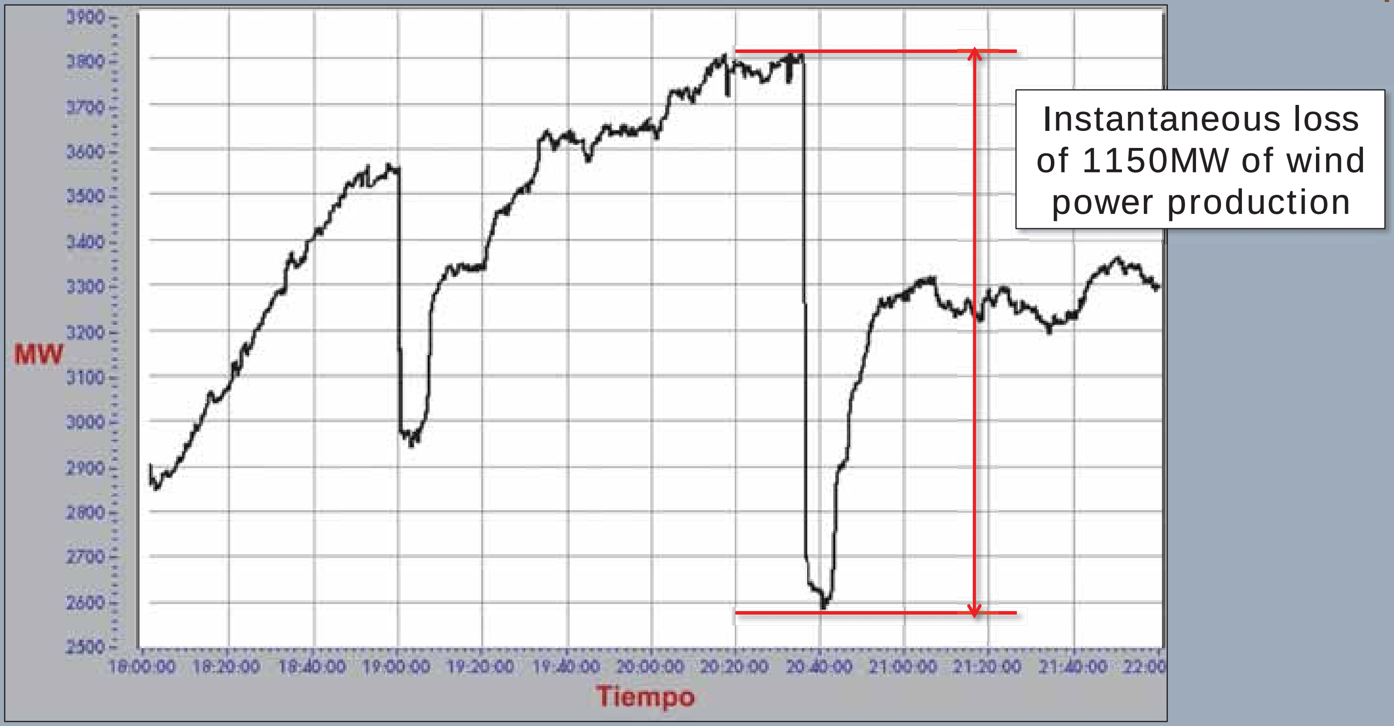
Incidents in wind power production

Wind power production in Spain (Aug 1st, 2005)



Courtesy of REE

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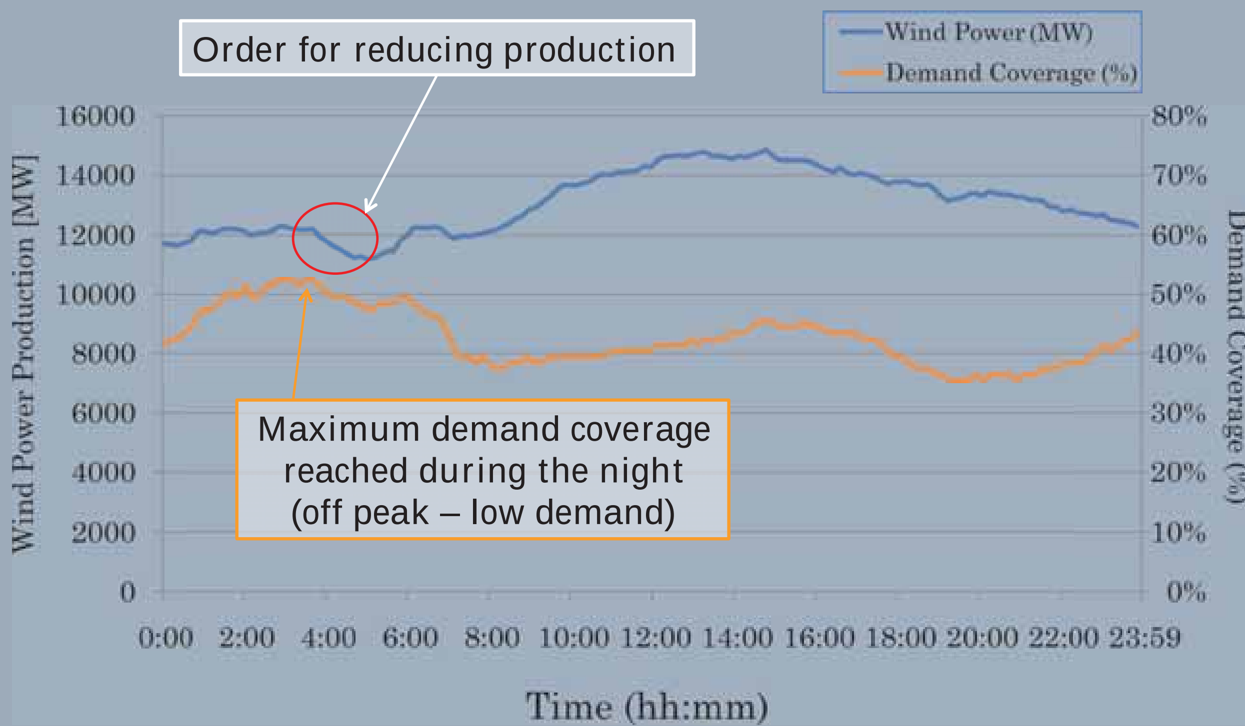
TSO order for reducing wind power

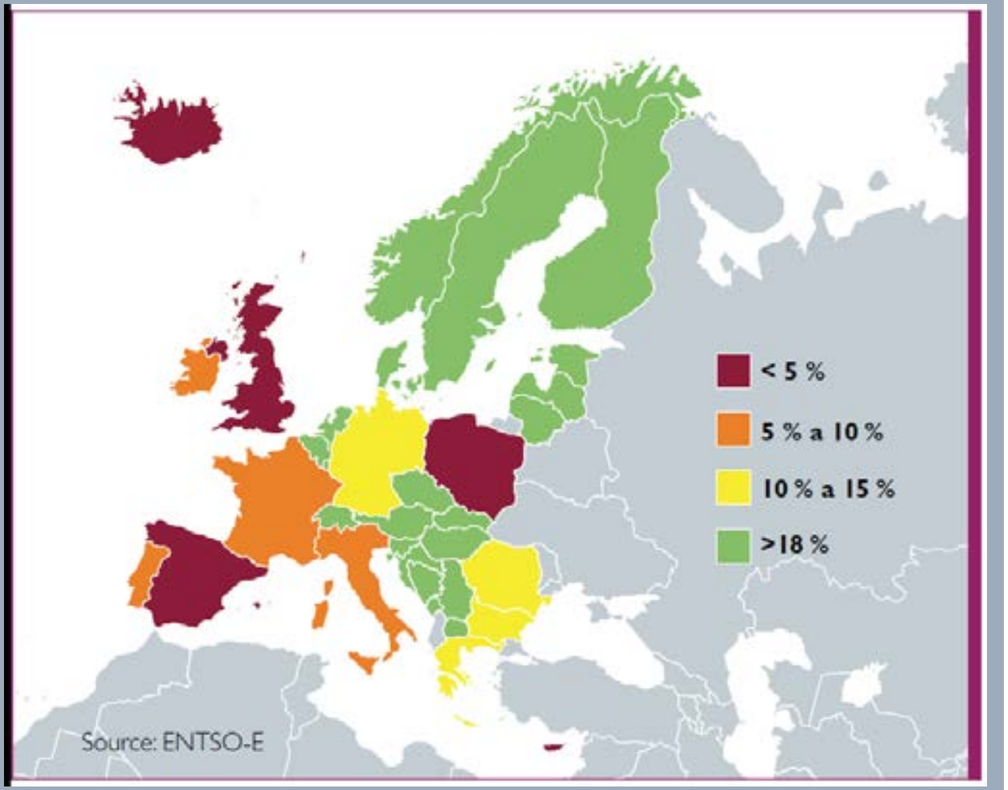
Nov 9th, 2010. Spain



Available energy not used!

SPAIN VS DENMARK

- Why this "fear"? In other countries as Denmark, the instantaneous demand coverage can reach >100%
- Differences in, e.g. the **interconnection ratio**
- Spain has in 2011 less than 5% of the installed generation capacity, Denmark has more than 18%



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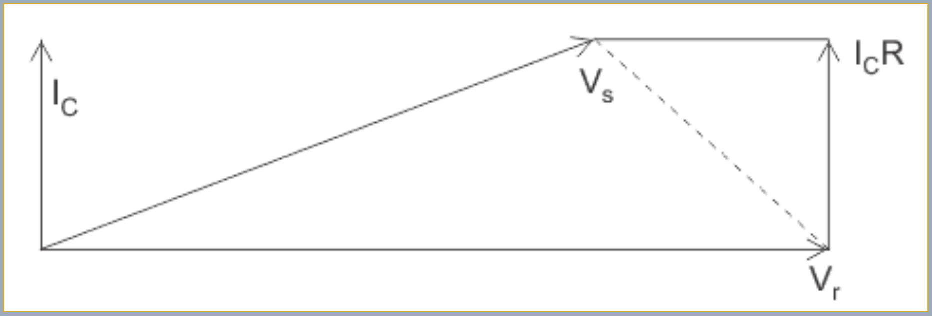
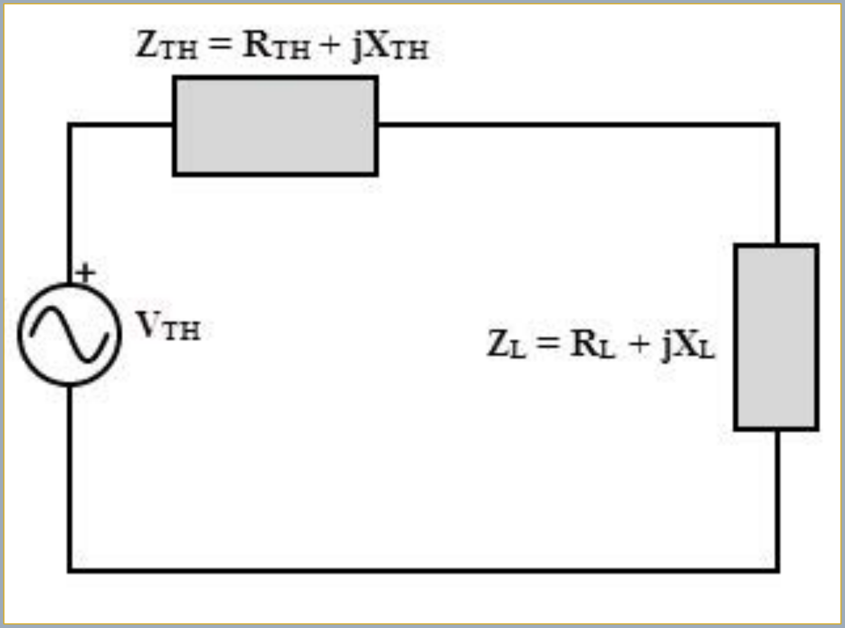
POWER GRIDS – DIFFERENCES

- Interconnection ratio
- Robustness of the grid, how constant the voltage is
- Harmonics
- Reactive management!
- Electromechanical studies are more complex in weak grids





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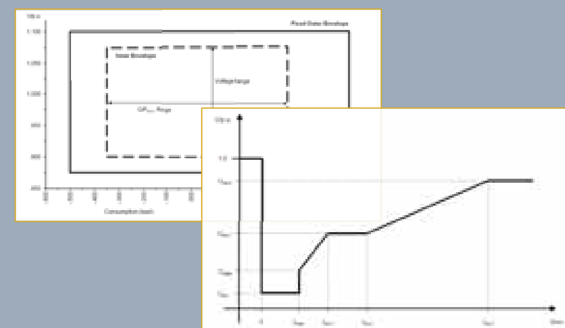


4. Development of Guidelines / Grid Codes

5. Conclusions & Future Work

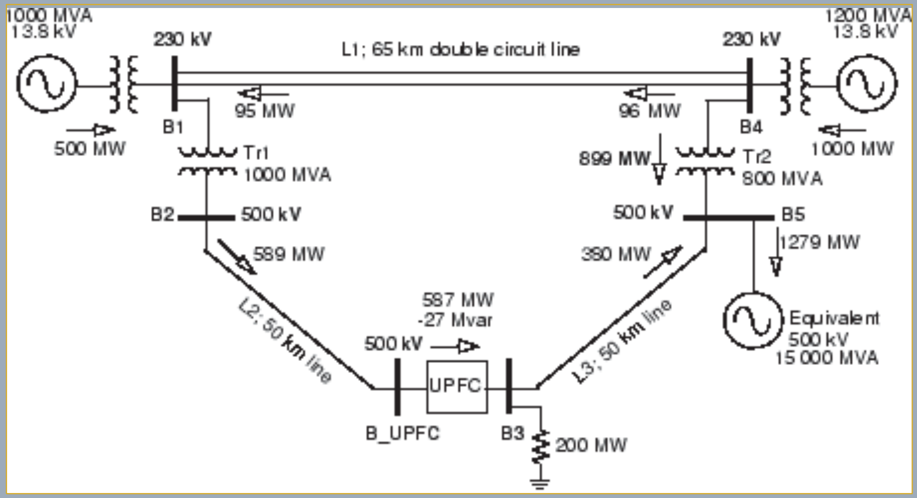
WHAT CAN WE DO? TO STUDY!

- **Steady-state studies**:
  - Power flows
  - Short-circuit analyses
- **Transient studies**:
  - Electromechanical transients
  - Electromagnetic transients
- **Power Quality studies**:
  - Voltage fluctuations
  - Harmonics

- **Modelling the renewable power plant** taking into account all the data of the cables, transformers… depending on the characteristics of each study
- **Tools**: PowerFactory, PSS®E, PSCAD, ATP-EMTP, Matlab…

STUDIES

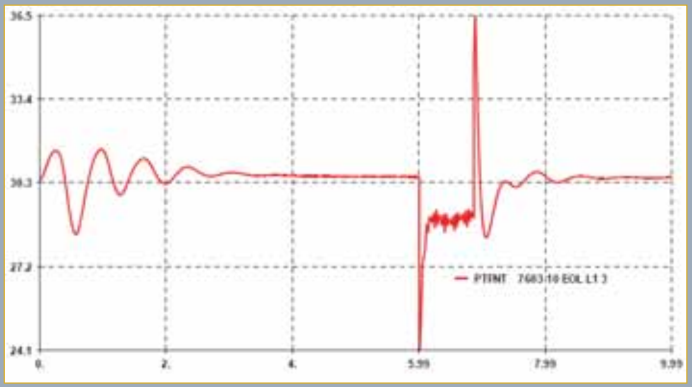
- **Steady-state studies:**
  - **Power flows**: to check the effect over the voltages in the buses nearby the power plant and the line capacity of the lines



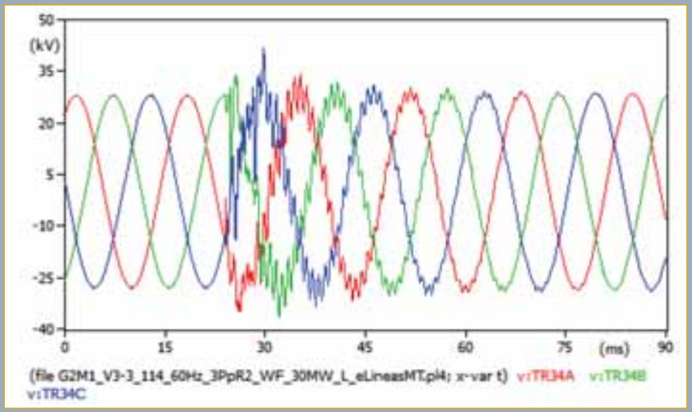
  - **Short-circuit analyses**: to verify the appropriate sizing of the breakers and switches located nearby the new power plant

STUDIES

- **Transient studies**:
  - **Electromechanical transients**: analysis of the response of the new plant in the event of voltage dips, set-point changes, etc.



  - **Electromagnetic transients**: analysis of overvoltages when energizing lines, transformers, etc.



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STUDIES

- **Power Quality studies**:
  - **Voltage fluctuations**: based on the emission of a single wind turbine or a PV inverter and the layout of the power plant, the flicker emission of the power plant is estimated.
  - **Harmonics**: in the same way, the harmonic emission in the point of connection is estimated. Special work presented in the following slides

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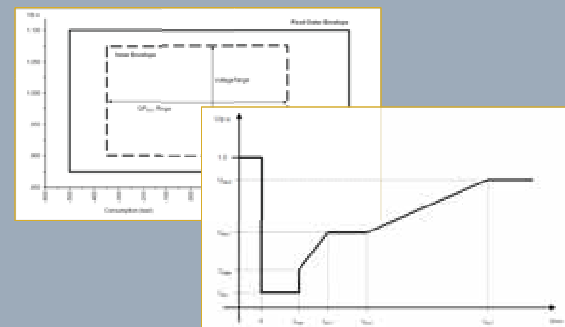

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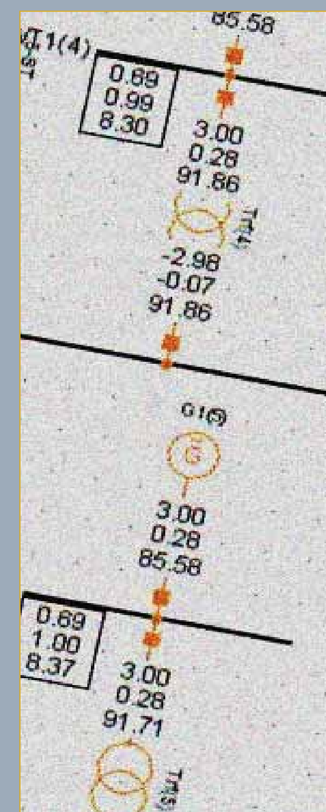
EXPERIENCES – HARMONICS

- Let's start somewhere in Latin America
- Harmonic studies, modelled in PowerFactory of DIgSILENT
- Scenarios characterize all the modes of the wind power plant (same study can be done for PV plant)
  - 12 cases per power factor.
  - Power factor of 0,95 capacitive, 0,95 inductive and unity.
  - 36 cases studied.

HOW DO WE DO IT?

- Measurements:
  - WT harmonic currents according to IEC 61400-21 ed.2
  - Harmonic voltages in the POC
- Data:
  - Cables
  - Transformers
  - Reactive power compensation device

- To do it accurately requires a big effort of researching!



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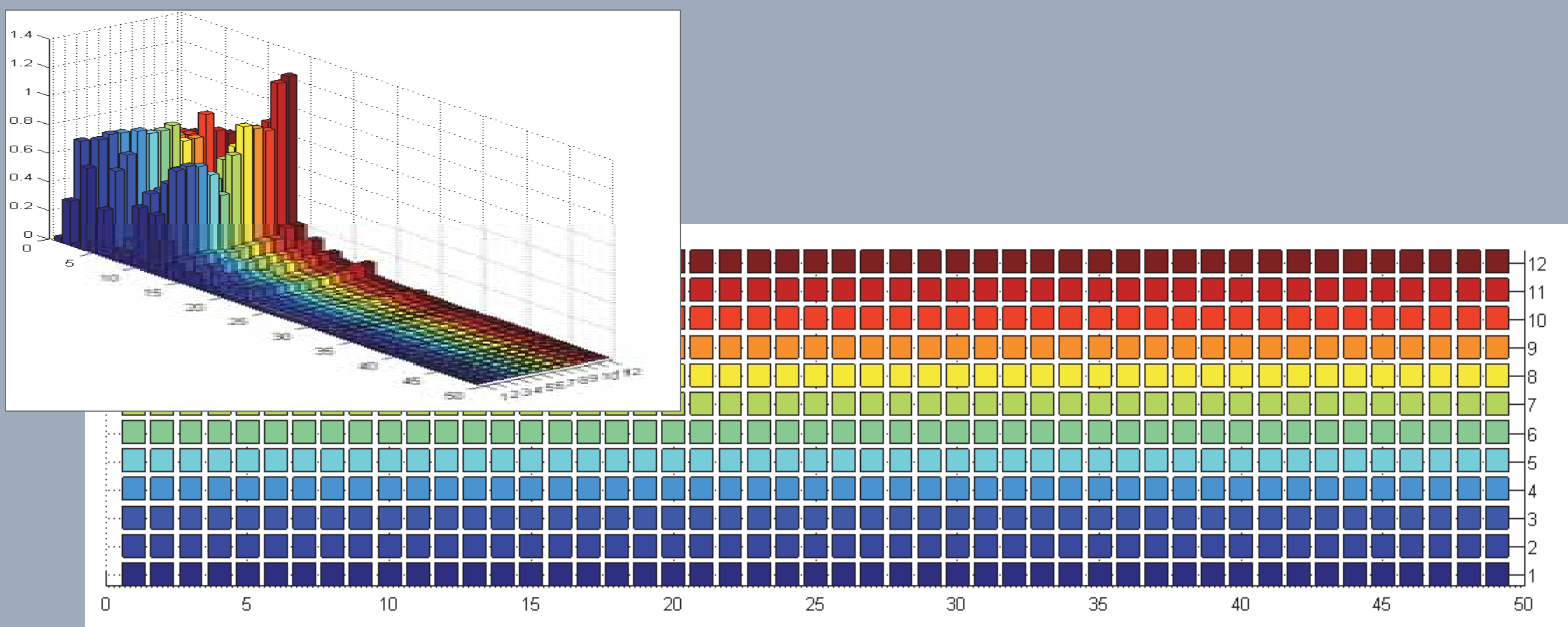
RESULTS

- Presentation of results



Case (level of production)

Harmonic order

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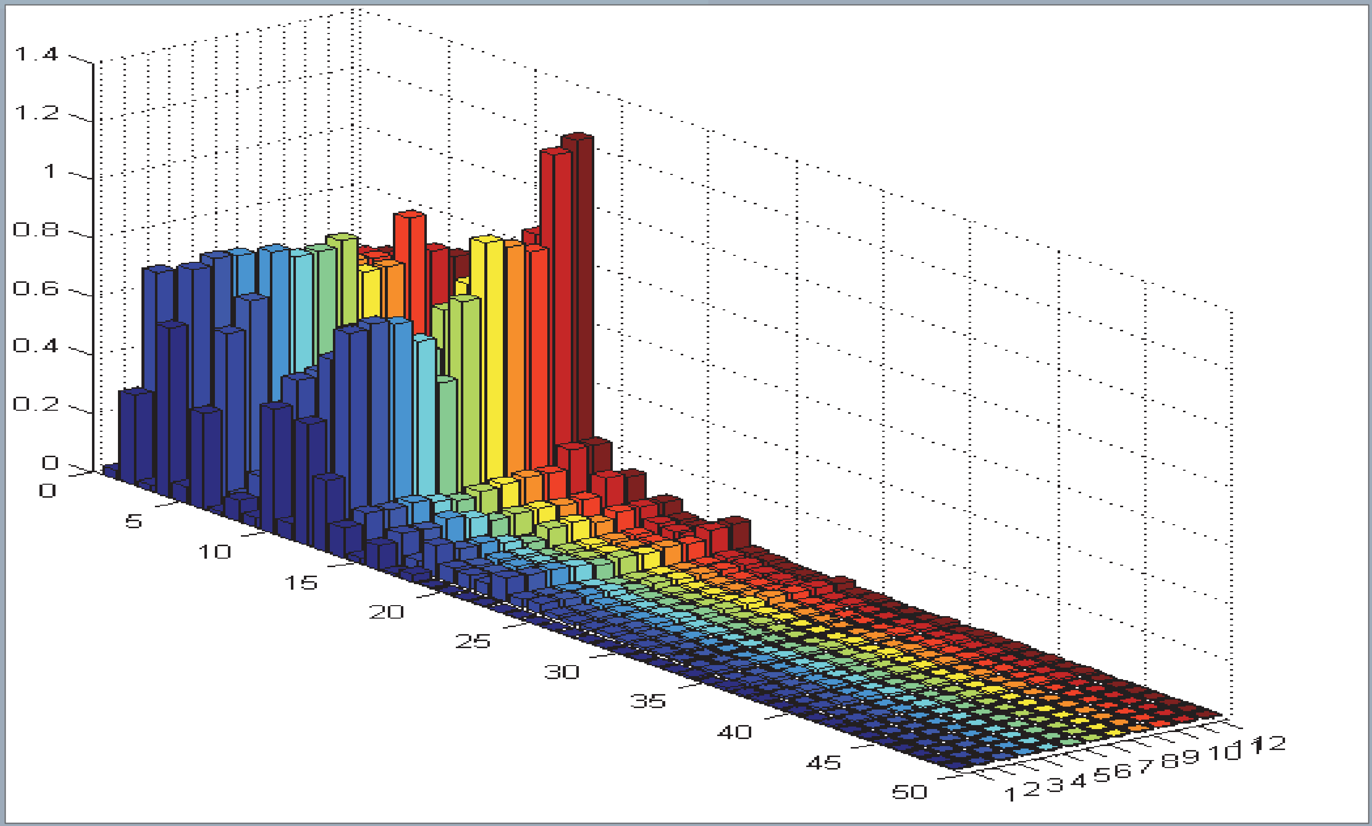
RESULTS – COSPHI 1



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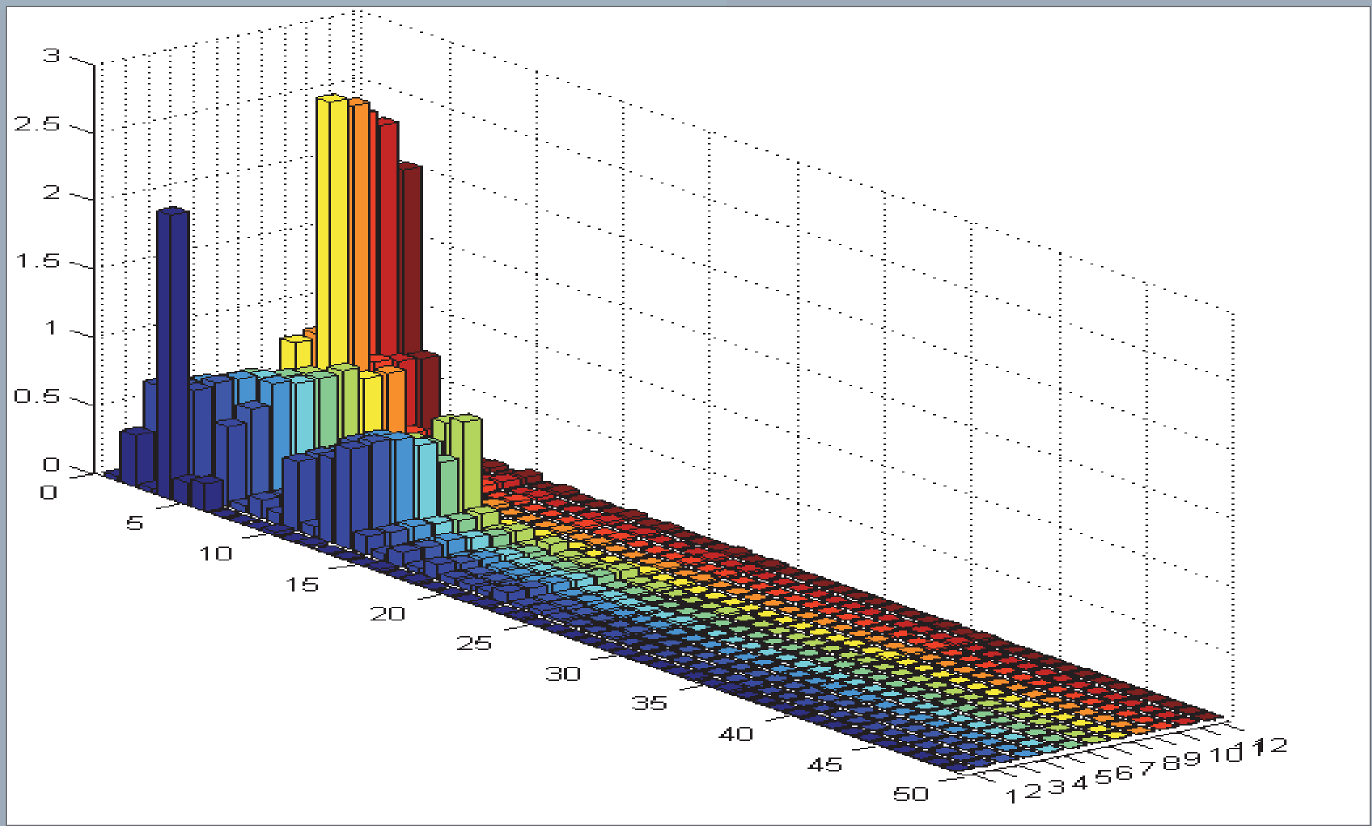
RESULTS – 0,95 CAP.



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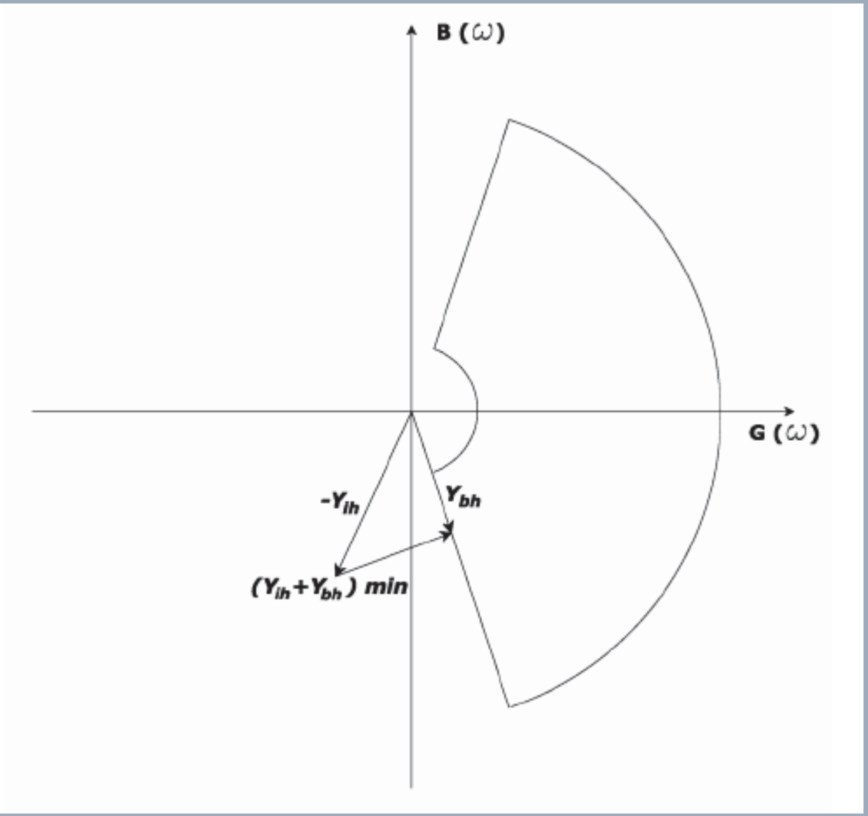
HARMONICS AROUND…

- Not easy
  - **Brazil**: It has to be considered how the grid will evolve in three years in advance
  - **South Africa**: the harmonic impedances of the grid should be set to some pre-defined values and the voltage limits then are translated to current limits



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COMPLETE WIND POWER PLANT

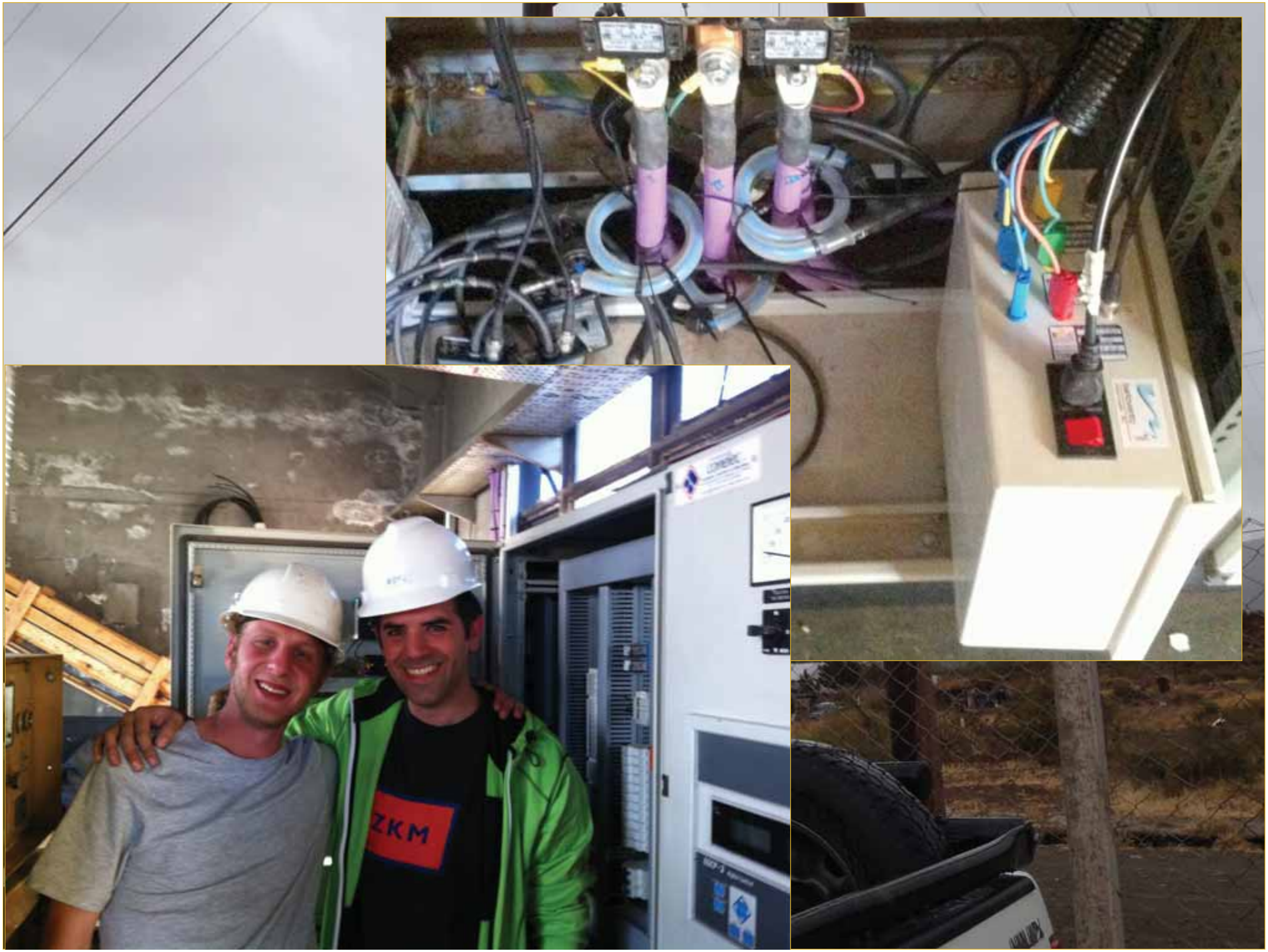
- According to **simulations**, the wind power plant of a certain project is not stable in the power system. The grid is too weak, just impossible
- Months of simulations, loops, iterations, adjusting the controllers of the wind turbine, of the wind power plant, improving the infrastructure, lines, etc.
- Most of the problems have been solved right now but not all, keep working

ON THE FIELD

- Great projects both big and small scale
- Sometimes **not enough studies** in small scale projects

ON THE FIELD

- **Project**: to remove old diesel generators in an electrical island. To change to wind power and a new diesel generator. To supply with constant electricity to 100 houses (and no noise) but…
- No detailed simulations were made
  - No simulations about the interaction of the controller of the wind turbine with the power network
  - No simulations of commissioning tests
- No estimations about flicker or harmonics were made at first
- The system did not work at first
- Let’s solve it

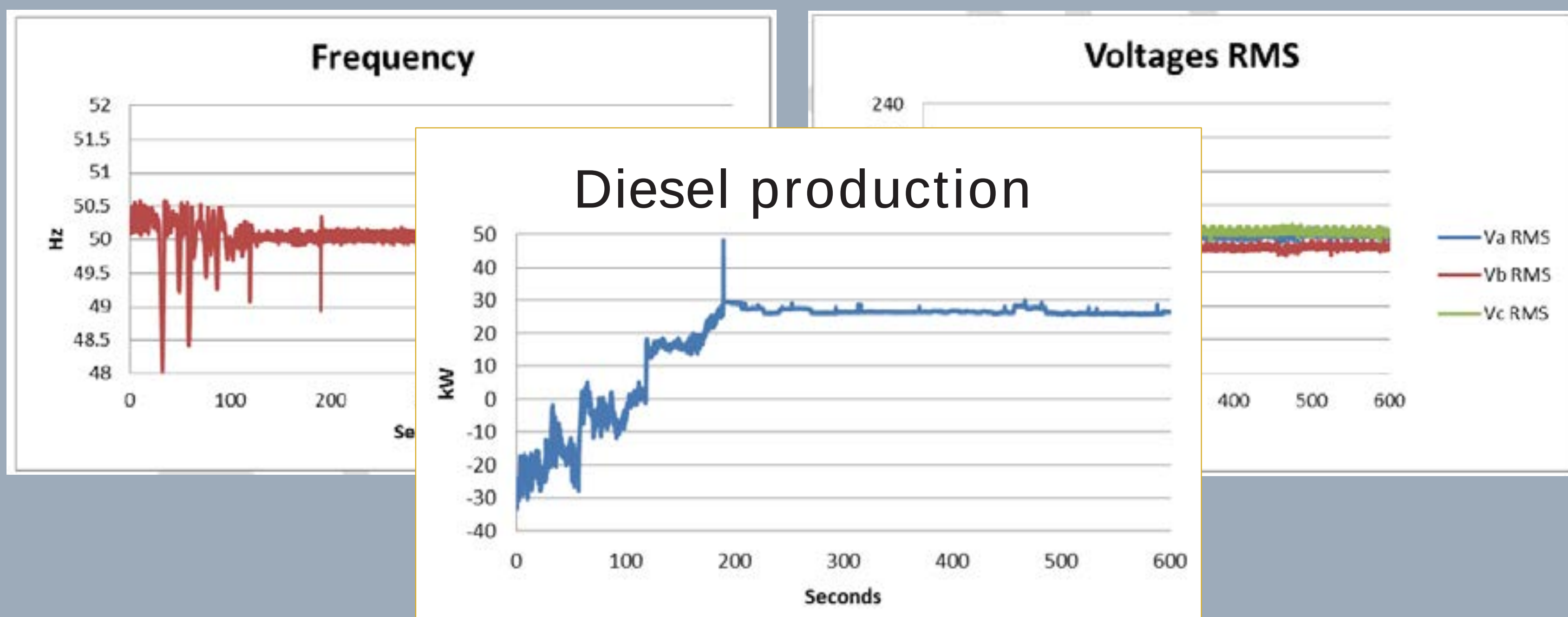

ZKM

SUCCESS?

- After measuring and months of work, the controller was adapted and the dump load of the diesel stabilized finally the grid
- Commissioning tests were agreed to check the behavior of the system
  - Black start
  - Trip of wind turbines
  - Trip of full load
  - ...

COMMISSIONING TESTS

- Wind – diesel system, trip of wind turbines



PV EXPERIENCES

- Transformer failures in PV power plant
  - Inverter control failing introducing important current peaks
  - Dry-type transformers
  - Normal irradiance => abnormal production
  - Big stress in the transformers, insulation damaged.
  - Reduction of the transformer life, from 20 to 5 years.
- Designing a PV power plant
  - Problems in the evacuation line, weak or even 1-phase line!
  - Long distances to loads => voltage levels out of range
  - Maintenance, e.g. sand in the equipment, salt spray, etc.

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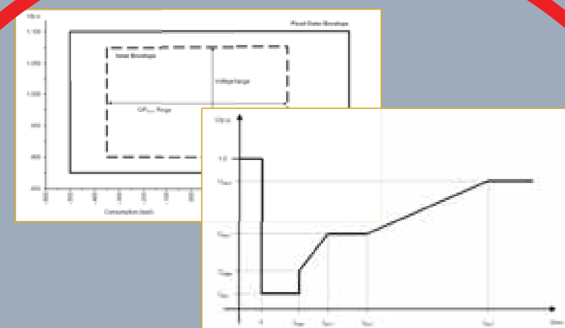

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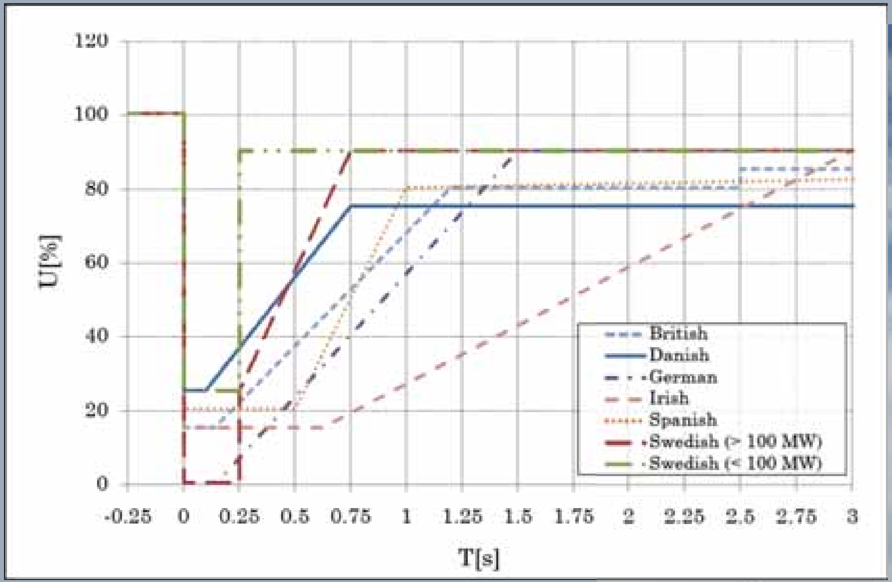
GUIDELINES, GRID CODES

- Voltage dip tests



GRID CODES

- Development of grid codes all over the world
- Most of the time they are very precise, sometimes they are copy of others more advanced… but designed for other conditions! (and sometimes with same typos)

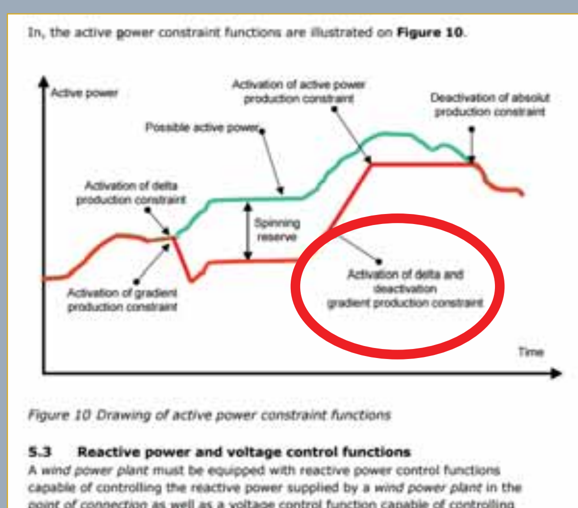

In, the active power constraint functions are illustrated on **Figure 10**.

Figure 10 Drawing of active power constraint functions

5.3 Reactive power and voltage control functions

A *wind power plant* must be equipped with reactive power control functions capable of controlling the reactive power supplied by a *wind power plant* in the *point of connection* as well as a voltage control function capable of controlling

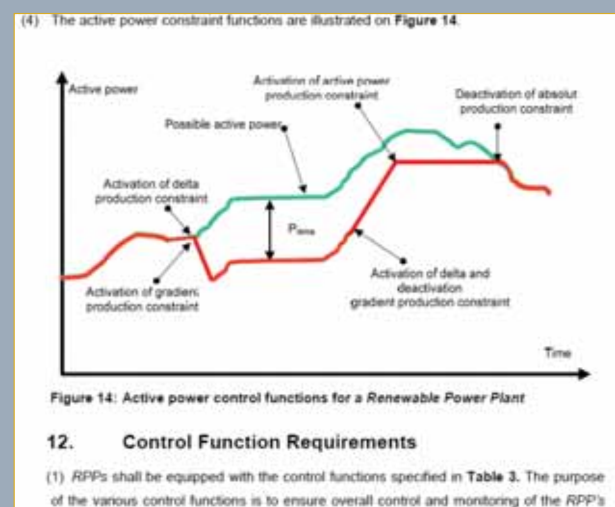

(4) The active power constraint functions are illustrated on **Figure 14**.

Figure 14: Active power control functions for a *Renewable Power Plant*

12. Control Function Requirements

(1) *RPPs* shall be equipped with the control functions specified in **Table 3.** The purpose of the various control functions is to ensure overall control and monitoring of the *RPP's*

INTERNATIONAL GUIDELINES

- IEC 61400-21
  - More tests, more capabilities to demonstrate, useful for TSO/DSO. 2 parts:
    - IEC 61400-21-1: wind turbines
    - IEC 61400-21-2: wind power plants
- IEC 61400-27
  - Modeling of wind turbines and wind power plants, relationship with future IEC 61400-21

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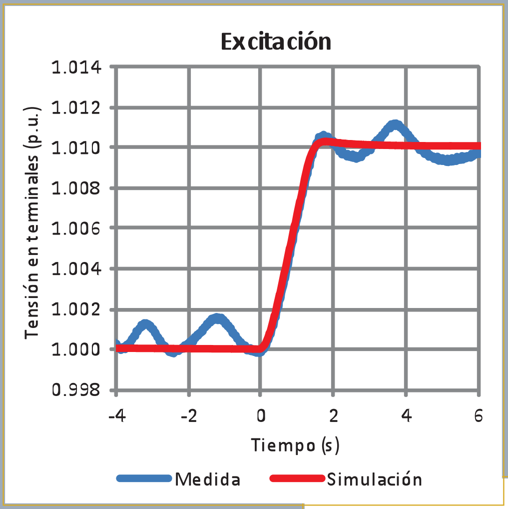
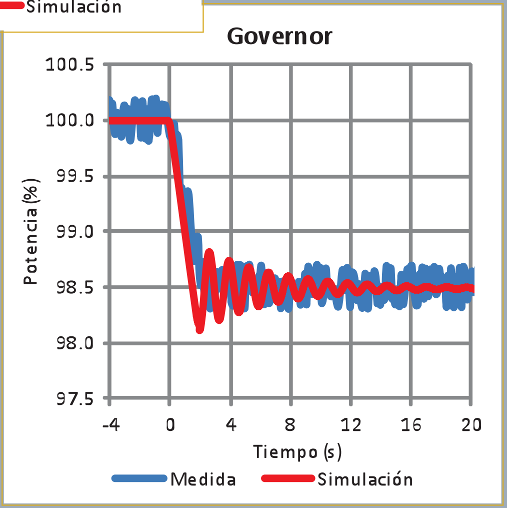
MODEL VALIDATION

- Importance of validation of different models
  - LVRT
  - Harmonics
  - Setpoint tracking
    - Active power
    - Reactive power

- TSO / DSO are the end-users of them. With such complex power grids, the use of validated models are becoming an important topic





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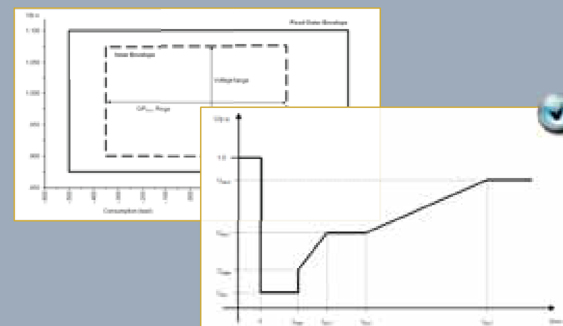

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CONCLUSIONS, FUTURE WORK

- We need renewable energy, but... what about the integration?
  - We need studies
  - Detailed simulations
  - Improving grid codes => improvements in the technology
  - **Reinforcing the infrastructure**

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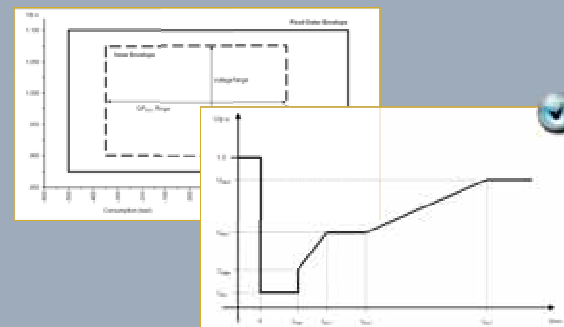

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THANKS FOR THE ATTENTION!

QUESTIONS?

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