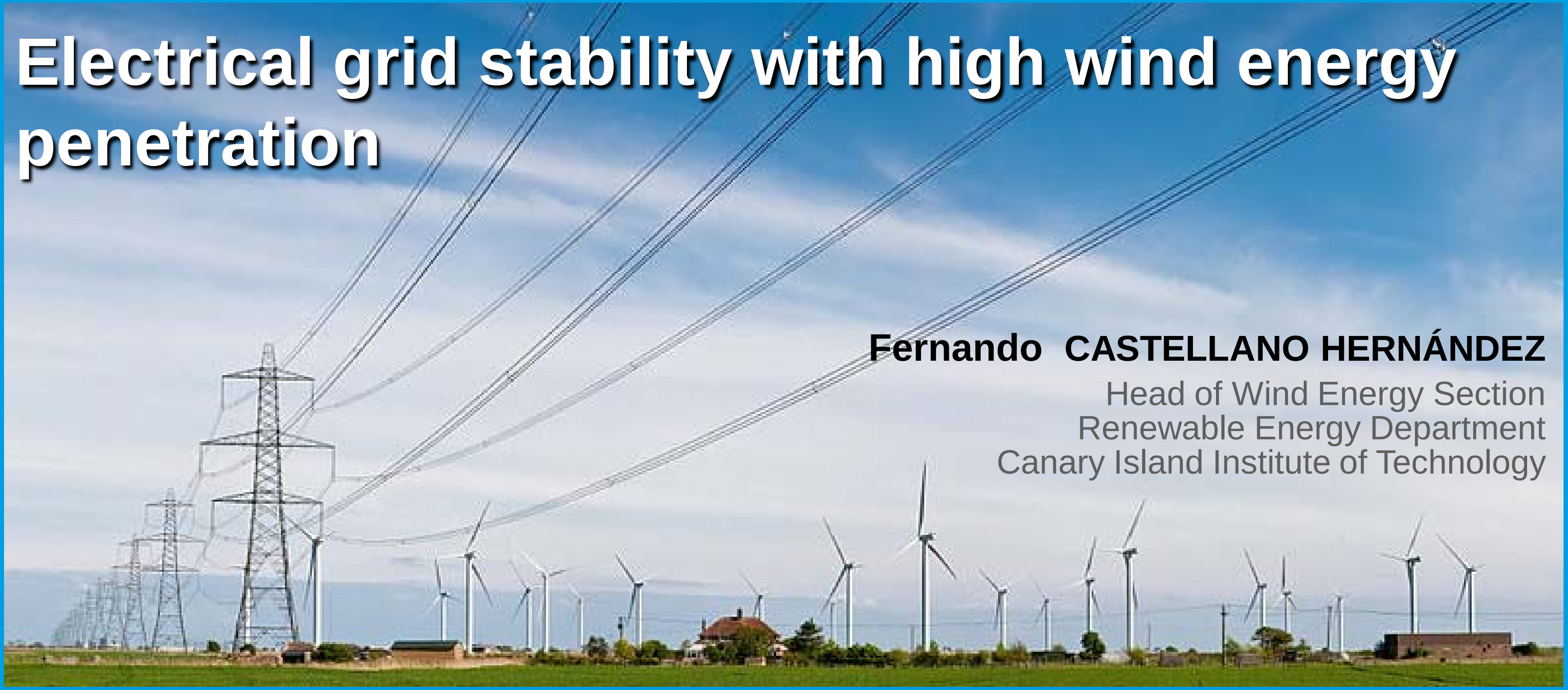
ECOWAS Regional Centre for Renewable Energy and Energy Efficiency
Centre Régional pour les Energies Renouvelables et l'Efficacité Energétique de la CEDEAO
Centro Regional para Energias Renováveis e Eficiência Energética da CEDEAO

ECOWAS Regional Workshop on WIND ENERGY

Praia, Cape Verde. November 4 – 5, 2013

Electrical grid stability with high wind energy penetration



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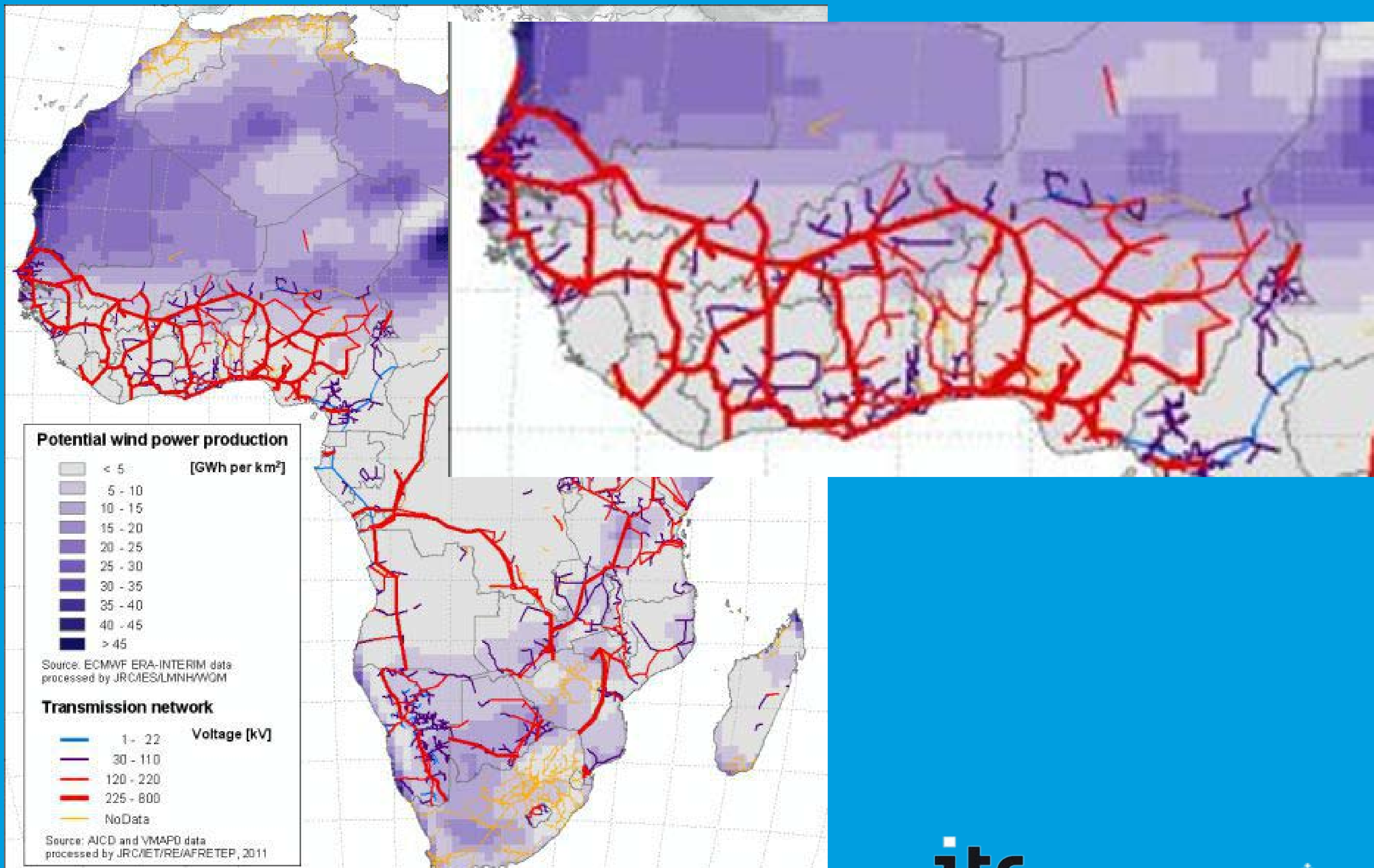
Outline

1. **Wind energy production:** perspectives and "problems"
2. **Dynamic grid stability:** electric grid parameters, quality supply
3. **Electrical network:** wind energy limitations and codes
4. **Grid studies methodology**
5. **Case study:** Lanzarote-Fuerteventura system & Corvo Island

Wind energy production: perspectives in Africa

- **Wind energy potential vs. African electric network**



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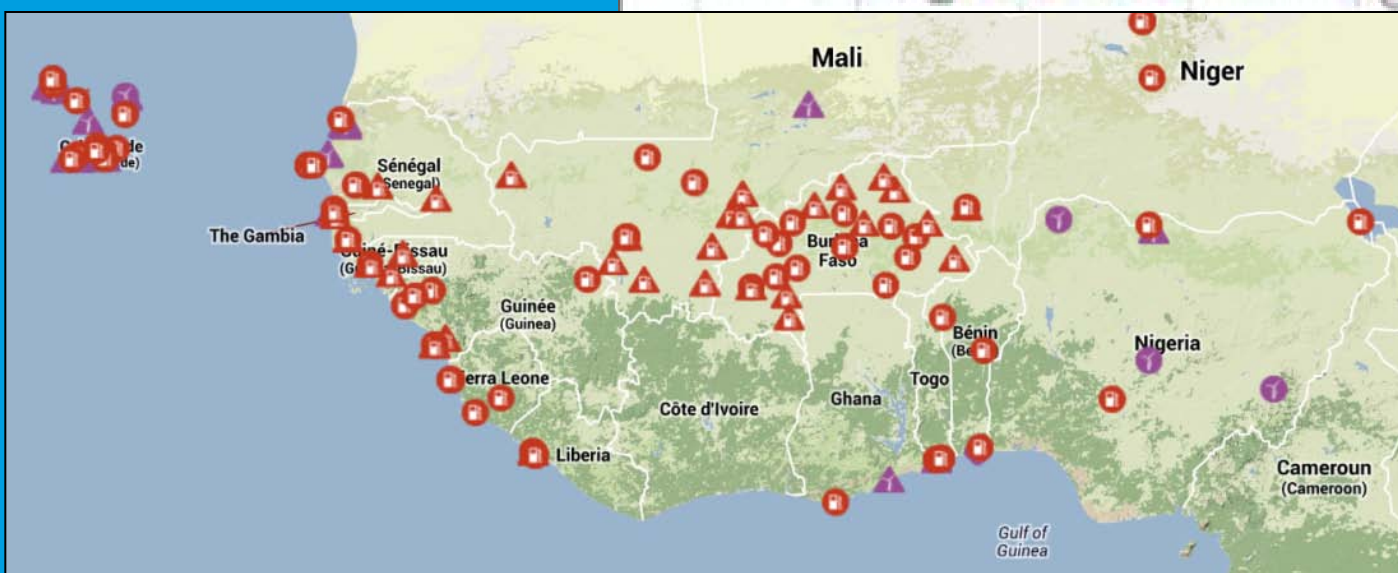
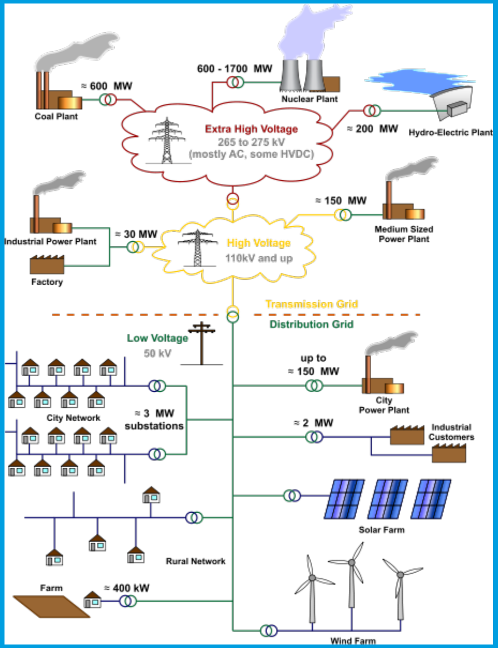
Wind energy production: perspectives in Africa

- **Wind energy potential vs. African electric network**



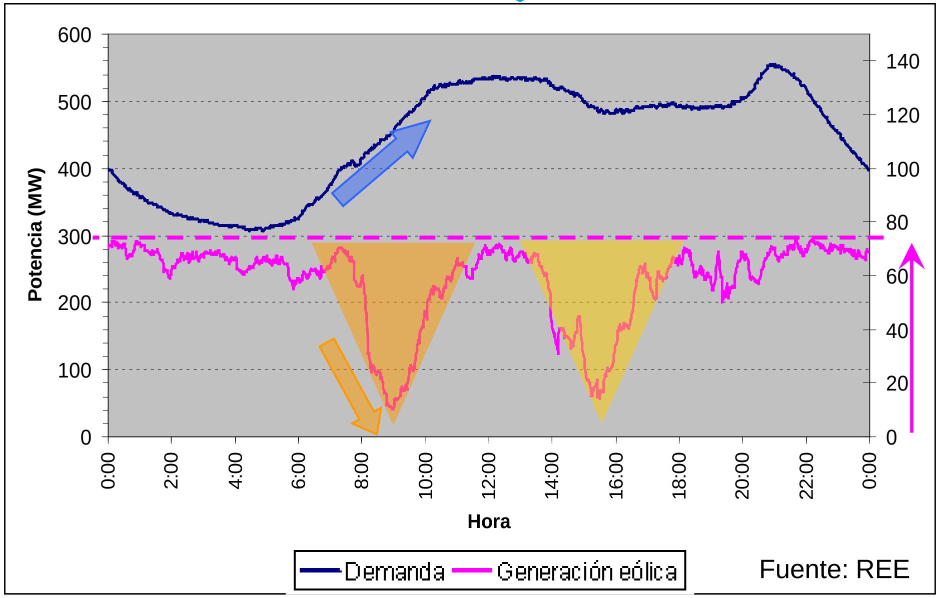
Wind energy production: concepts

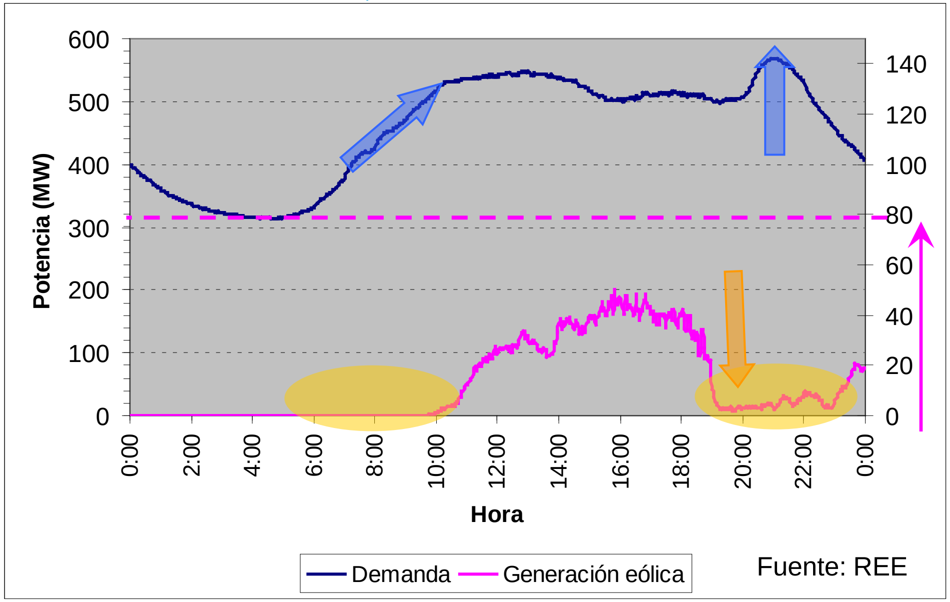
- **Penetration**, refers to the fraction of energy produced by wind compared with the total available generation capacity.
- **Operating reserve** is the generating capacity available to the **system operator** within a short interval of time to meet demand in case a generator goes down or another disruption to the supply. → "compensate wind power plants generation variation".
- The **limit** for a particular grid will depend on the existing generating plants, pricing mechanisms, capacity for energy storage, demand management, dimension of the grid and other factors. **Around 20%** is accepted. To obtain 100% from wind annually requires substantial long term storage
- The increased **predictability** can be used to take wind power penetration from 20 to 30 or 40 per cent.



Wind energy production: perspectives and “problems”

MISMATCH BETWEEN WIND GENERATION AND DEMAND





- Limits the integration capacity of wind energy in the electric network
- Requires the actuation of conventional spinning generation
- Deviation in wind energy production means over-cost for the electric bill

NON CONTROLLABLE GENERATION → NO ELECTRICITY SUPPLY GUARANTEE

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Wind energy production: problems

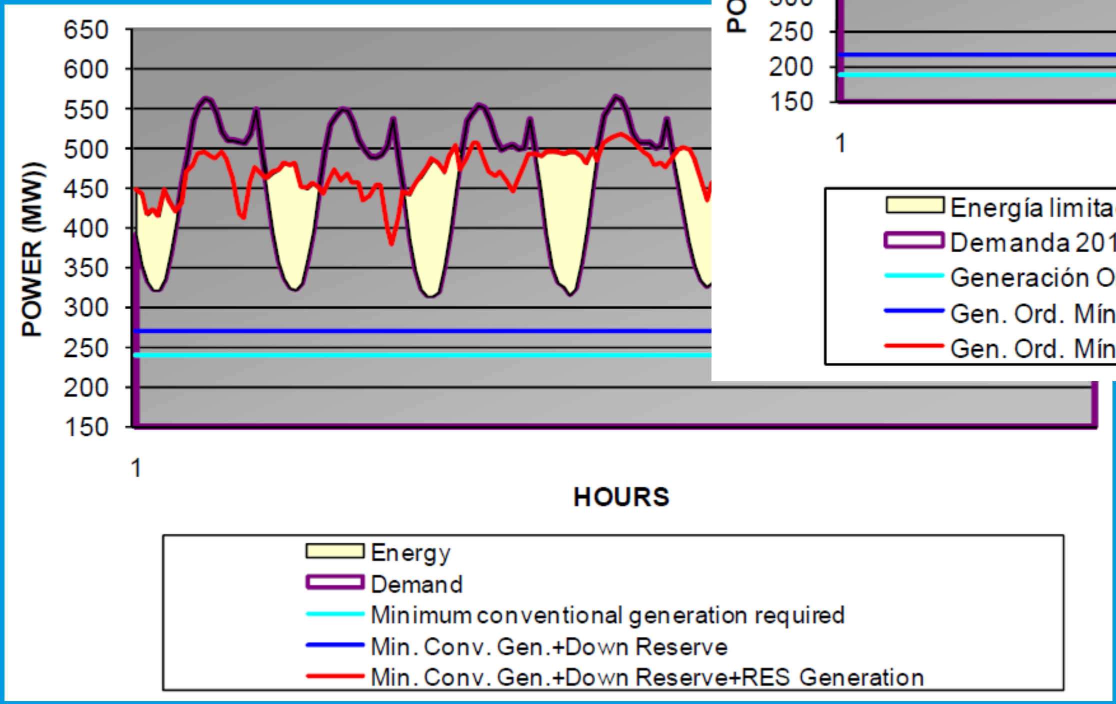
- **GENERATION LIMITATION RISK**

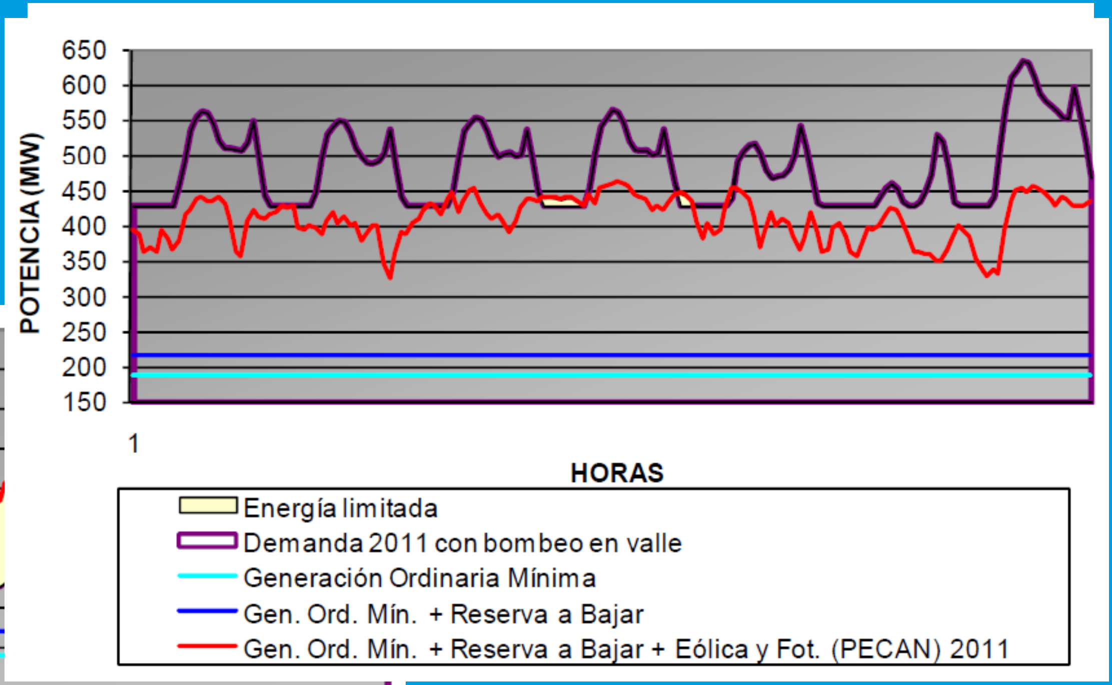
An electrical system could not assume the whole amount of RES energy produced in actual situation → Power demand vs RES generation

Solution:

energy storage systems

Demand coverage limitation





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Wind energy production: conclusions

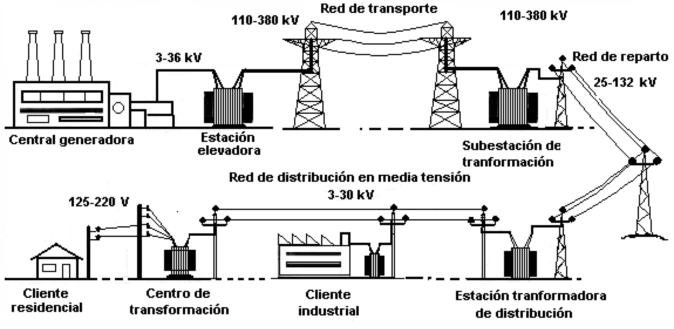
- **Demand coverage - premises**

1. Electric supply is an essential service
2. Electrical power systems only can work at any moment when there is an instantaneous balance between generation and demand

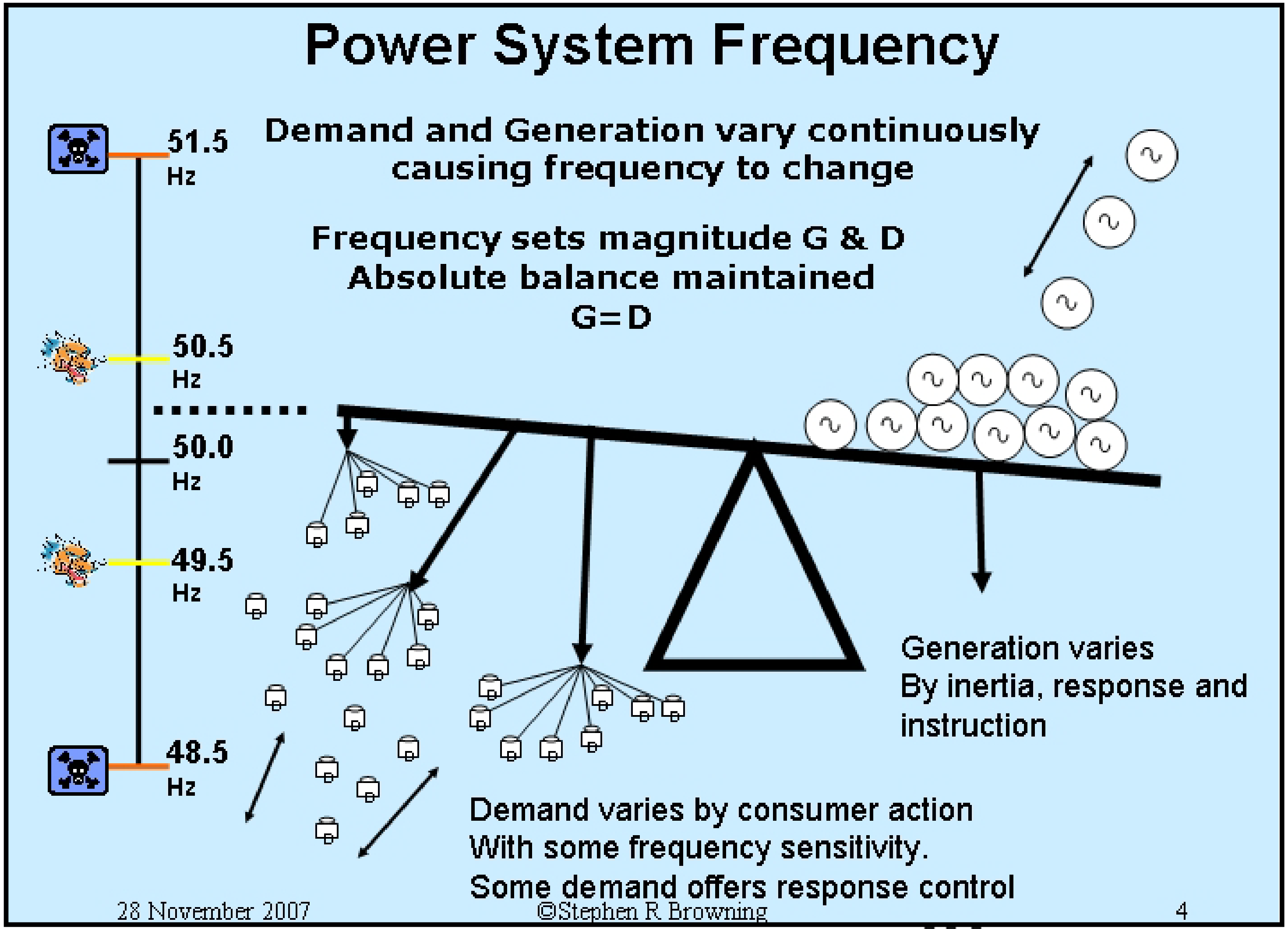
- **Consequence**

Careful planning of the generation and protection systems to grantee the viability of the electrical system balance

STABILITY STUDIES FOR PLANNING AND VERIFICATION



Balance between GENERATION and DEMAND



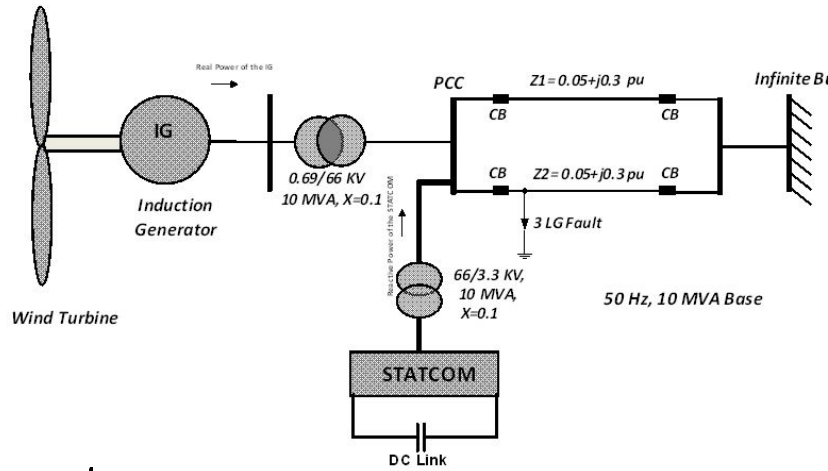
Electric grid parameters and codes

CRITERIA	LIMITS
Voltage level	+/- 10% de Un (Integrated over 10 minutes)
Quick voltage variation	+/- 8% de Un (Integrated over 3 seconds)
Overvoltage due to line-earth short-circuits	Un < 140 %
Voltage harmonic distortion	THD-U < 8%
Frequency variation limits on steady state conditions	49,85Hz/50,15Hz (Integrated over 5 minutes)
Frequency variation limits on contingency situations	+/- 2% de 50Hz; 49Hz/51Hz (Integrated over 240 ms)

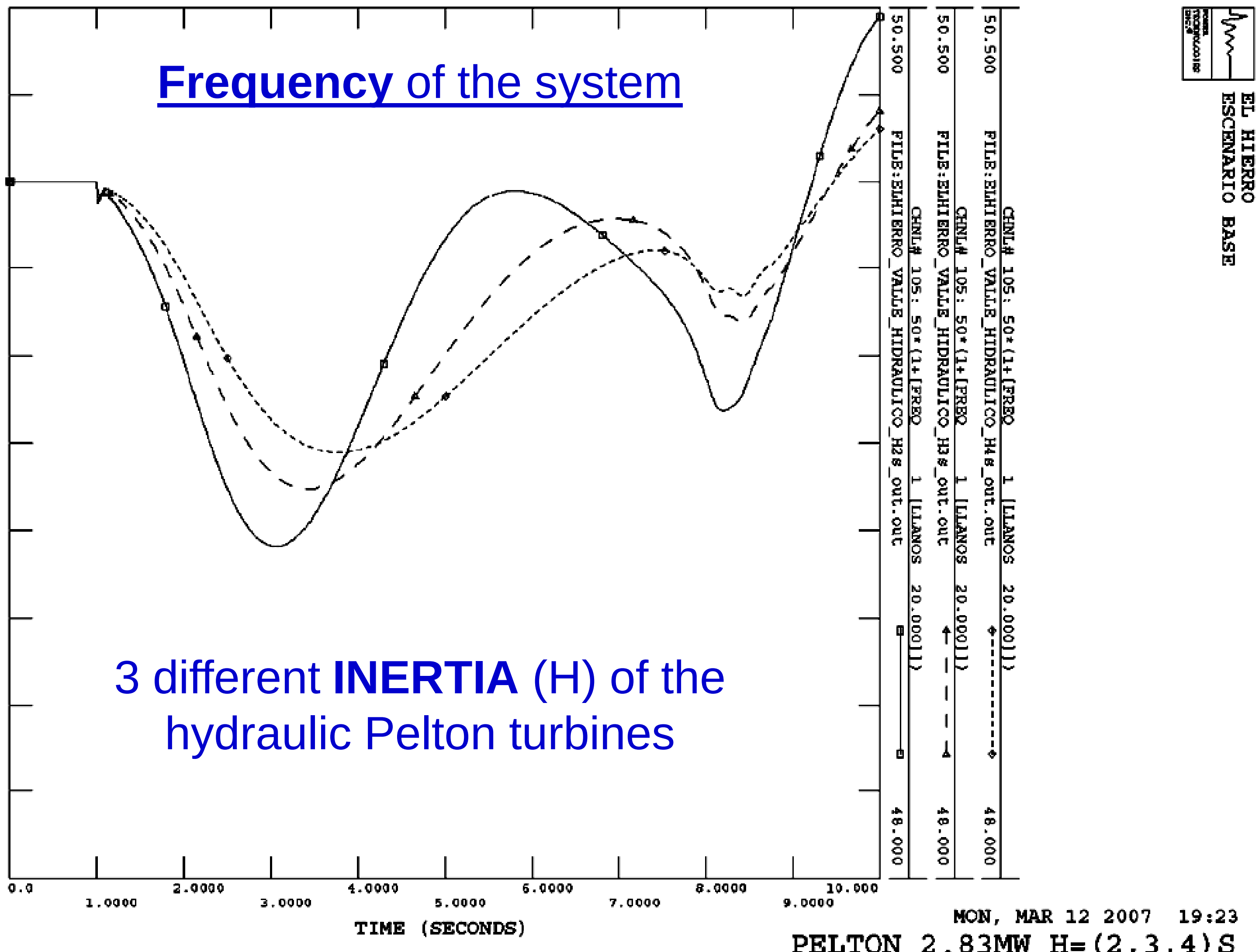
Any modification on the electric network, due to enlargement, entry of new equipment or change in exploitation criteria could cause codes breaking of any security requirements or technical limitation.

Active systems that participate in modern electrical grids have to offer COMPLEMENTARY SERVICES to guarantee stable exploitation:

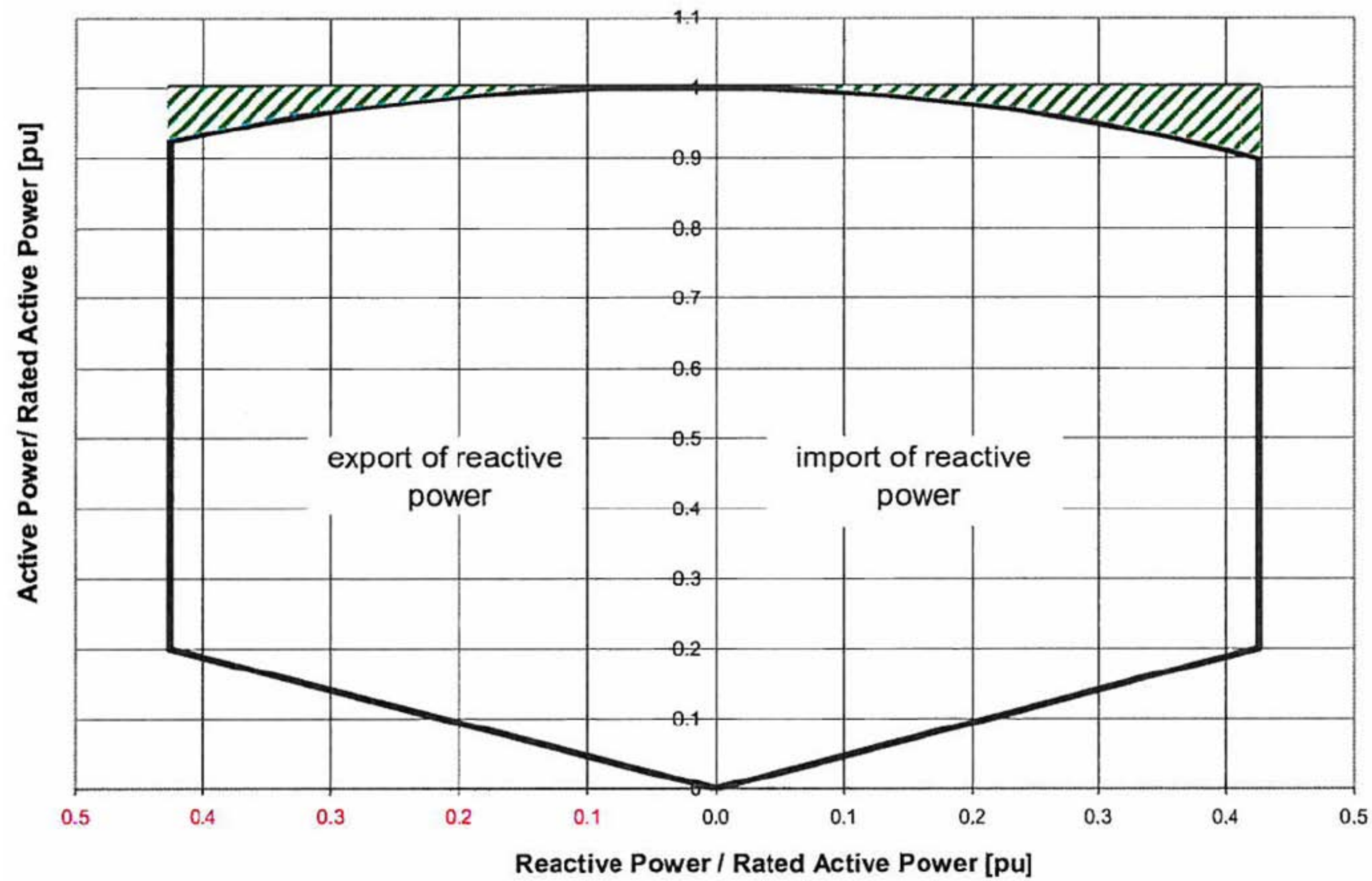
- Voltage control
- Inertia
- Primary and secondary regulation
- Capacity of supply short-circuit current
- Short and medium term energy storage
- Demand side management



Start-up of a 500 kW pump in a valley scenario with hydraulic generation:

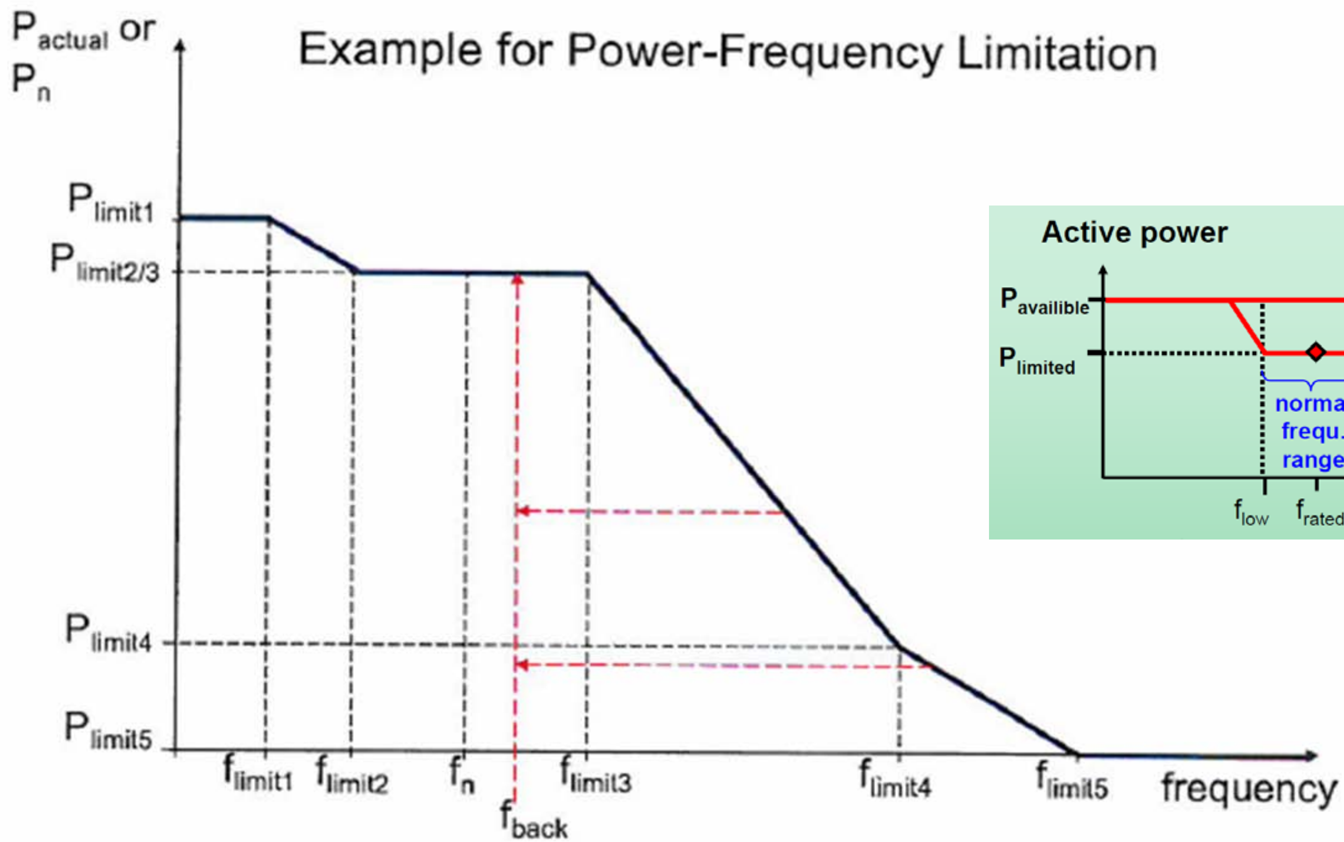


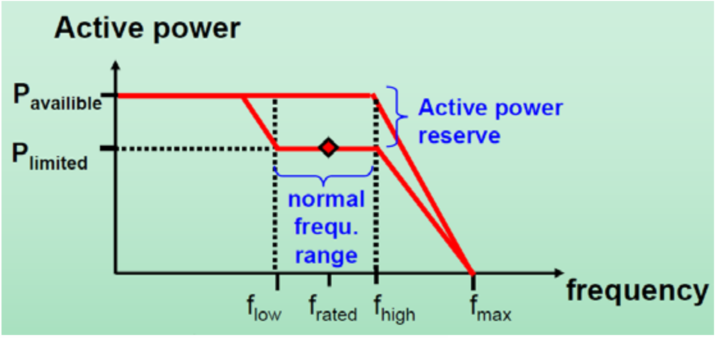
Reactive capacity regulation of wind energy converters (WEC):



Increase in grid renewable penetration → higher power control capacities

WEC power-frequency regulation:





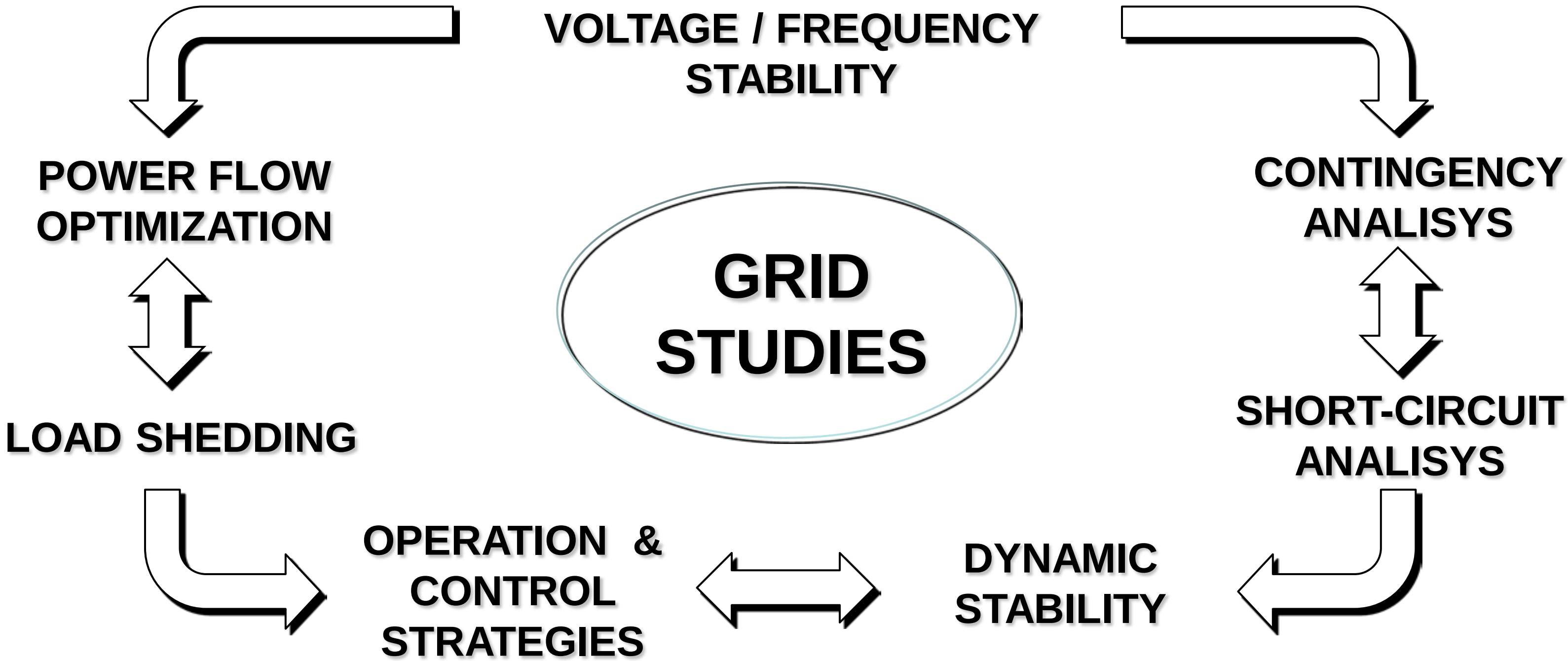
: "Static" Power-frequency control

Criteria (ex.):

1. **Voltage at the electrical grid nodes** should stay between +/- 7% during lost of 100% RES production
2. **Voltage variation during connection/disconnection** of the wind farm (in worst scenario) should stay under 5% Un.
3. **Power flow** on voltage control equipments (nodes) should never be inverted due to the increase of wind energy production
4. **50% of the conventional power capacity** should not be overpassed by the wind power for any node of the power line
5. **50% of the transformation capacity** of the substation should not be overpassed by the wind power connected
6. **5% of the short-circuit power** of the node/substation bus (in worst scenario) should not be supplied be wind farms

Grid studies methodology

Object: analysis of the critical scenarios in the electrical systems to ensure compliance of the codes, and to verify the security & quality guarantees



Optimal solution after several iterations

Steady-State Analysis

NODAL STUDY

- **Generation by nodes** → Transported power at **N-1** + off-peak demand
- **Installed wind power < ** 5% short-circuit power
- **Territorial criterias** → Energy infrastructure Planning

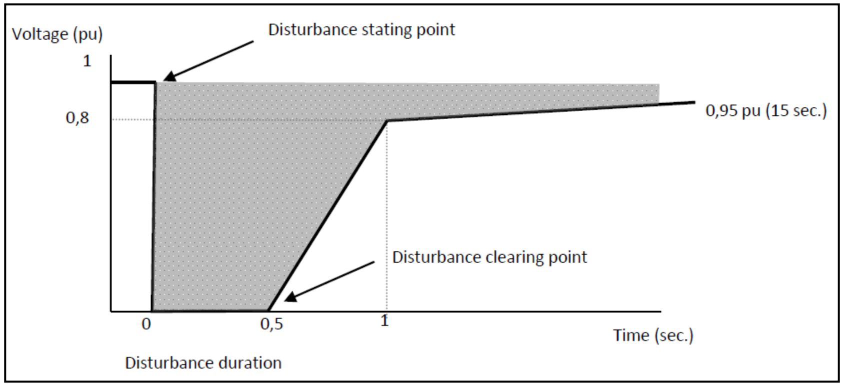
SYSTEM CAPACITY STUDY

- **Conventional power plants units** → minimum power, power factor
- **Voltage profile of the system**
- **Spinning reserve**
- **Transport network criterias**
- **Distribution network criterias**

N-1 criterion requires that the system be able to tolerate the outage of any one component without disruption

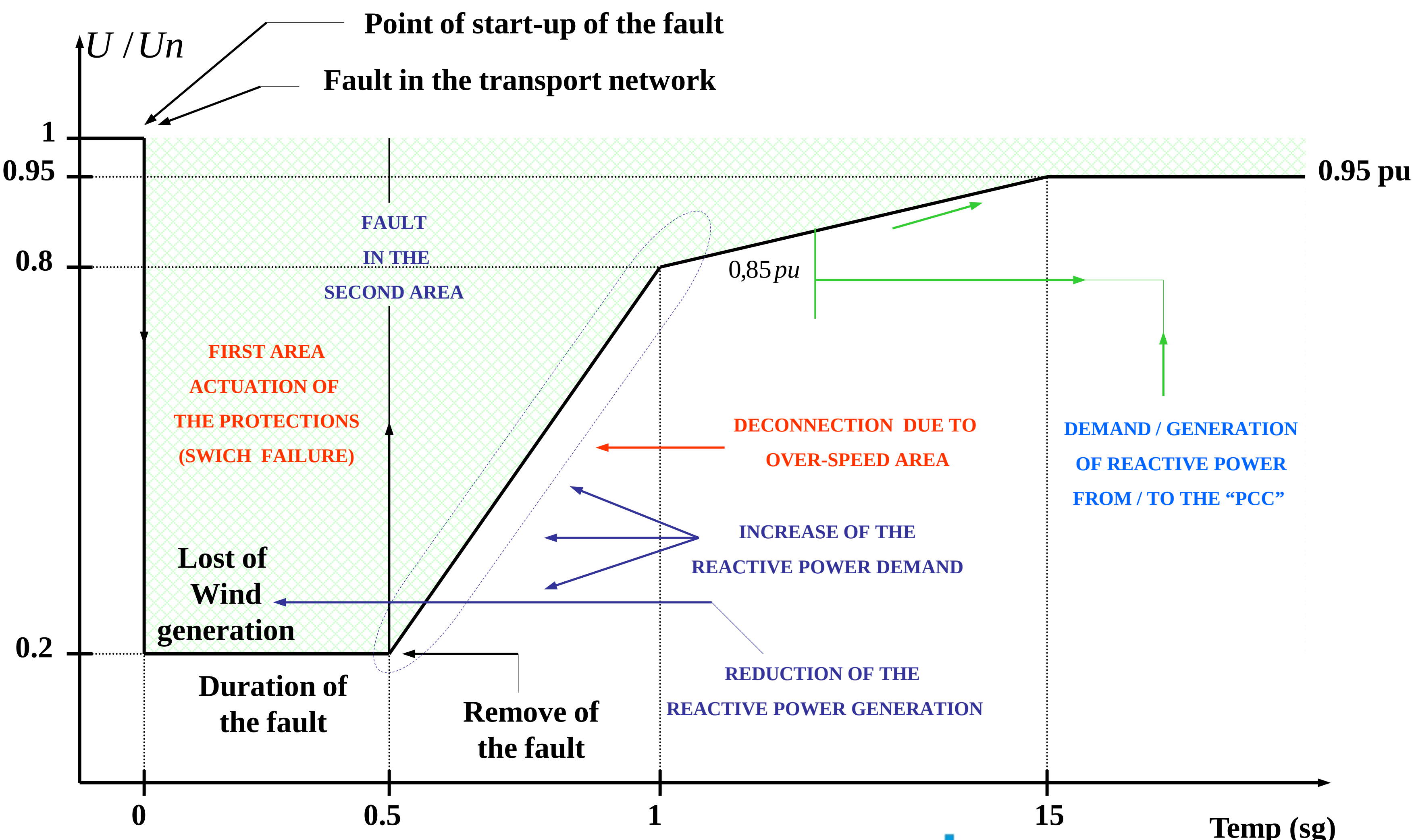
Dynamic Analysis

- Evaluation of the **feasible Steady-State Scenarios**
- Simulation of the grid on:
  - **three-phase short-circuits**
  - **lost of a conventional generation unit**
    (with & without wind generation, N-1 / N-2 criterion)
- **Oscillation of the power, overcharges & load shedding due to sub-frequency**

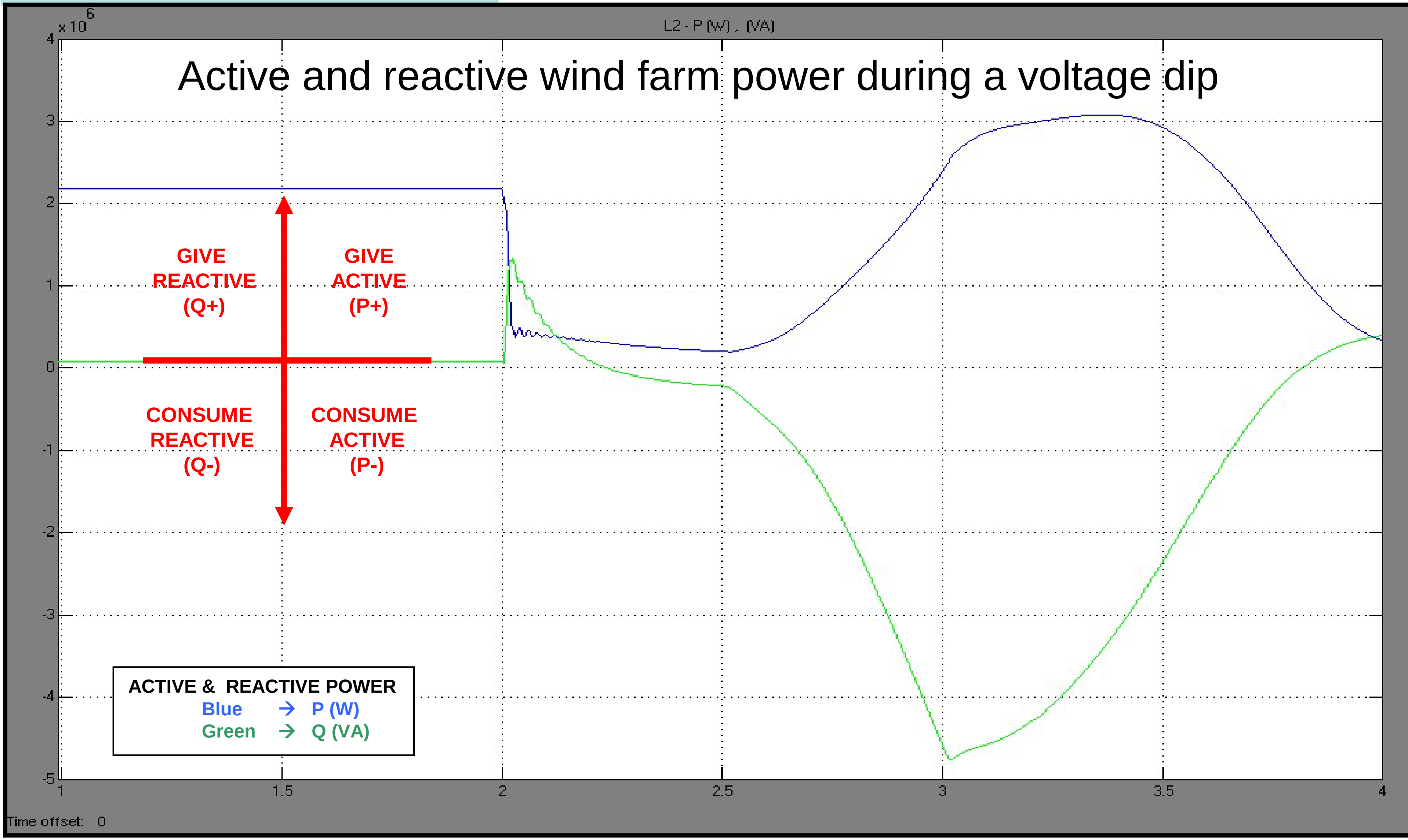


- **Voltage** (voltage dip) **& Frequency Behavior**

Voltage Dips (Sags)



Voltage Dips (Sags)



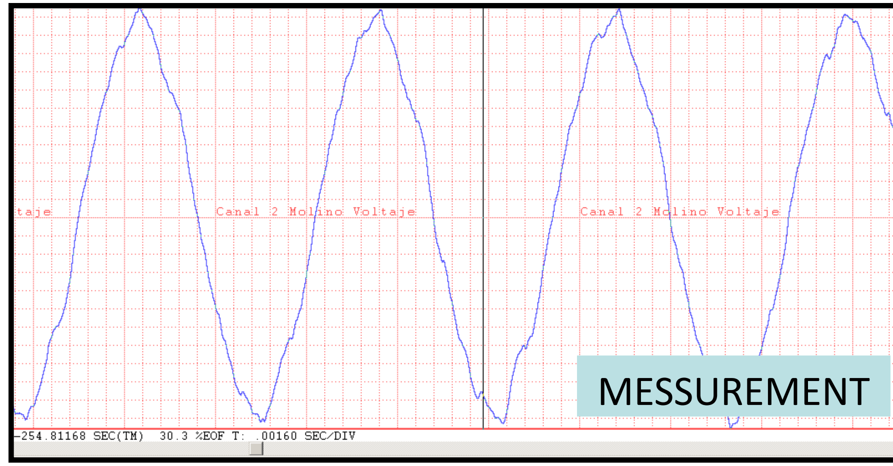
Harmonic study

Example of **current** harmonic distortion of a wind turbine

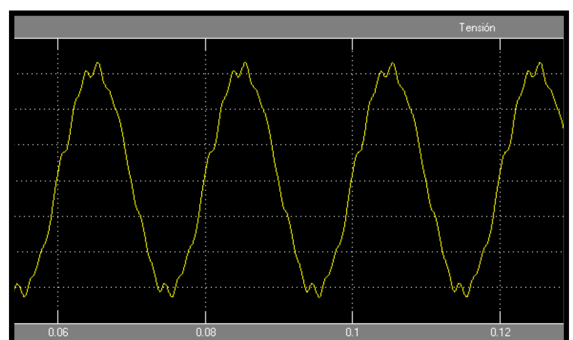
Order Ord-en	Harm. current [%] Corriente armónica	Output power [kW] Potencia producida	Order Ord-en	Harm. current [%] Corriente armónica	Output power [kW] Potencia producida	Order Ord-en
1			**11**	0.11	546	**21**
2	0.20	1171	**12**	0.10	1300	**22**
3	1.62	1140	**13**	0.17	230	**23**
4	0.14	1304	**14**	0.14	259	**24**
5	0.45	372	**15**	0.21	318	**25**
6	0.11	1295	**16**			**26**
7	0.47	295	**17**			**27**
8	0.12	1295	**18**	0.15	544	**28**
9	0.36	1171	**19**	0.10	1239	**29**
10			**20**			**30**
Maximum total harmonic current distortion: [% of I_n] Distorsión total máxima de corriente armónica					1.73	

Output power at maximum total harmonic current distortion: [kW] Potencia producida en la dist. total max. de corriente arm	1140

Example of **voltage** harmonic distortion in a weak electrical grid with high power electronics penetration (RES)



MESSUREMENT



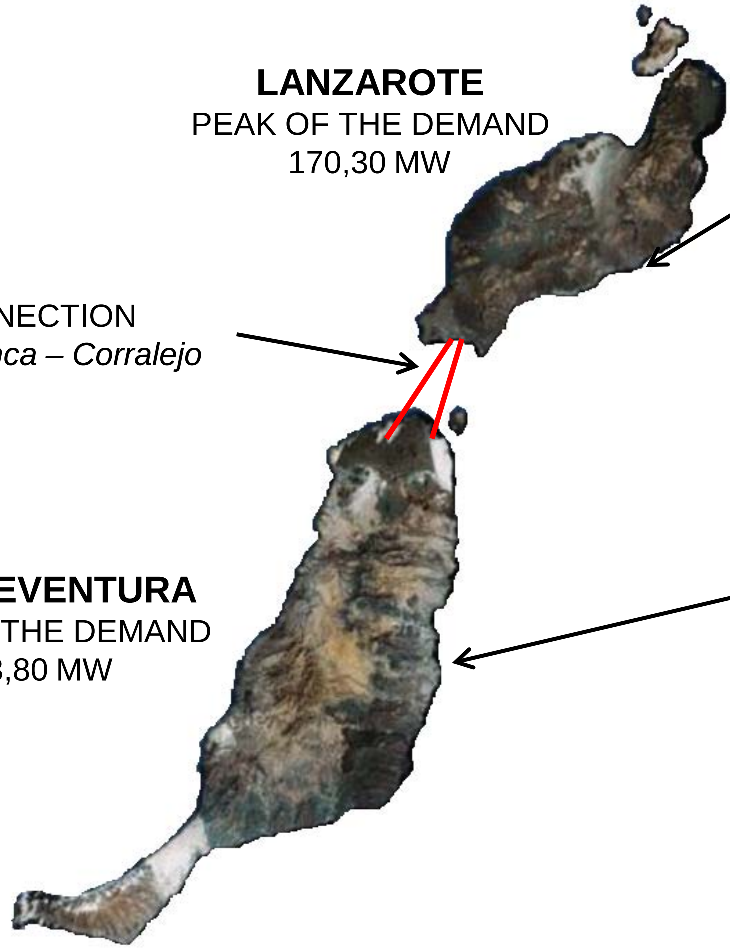
MATHLAB MODEL

CASE STUDY 1: Fuerteventura – Lanzarote electrical network

Planning: horizon 2017

LANZAROTE
PEAK OF THE DEMAND
170,30 MW

INTERCONNECTION
66 kV Playa Blanca – Corralejo



FUERTEVENTURA
PEAK OF THE DEMAND
123,80 MW

POWER PLANTS

PUNTA GRANDE
INSTALLED POWER: 244,24 MW
TECHNOLOGY: Diésel motor, Gas turbine

LAS SALINAS
INSTALLED POWER: 187,43 MW
TECHNOLOGY: Diésel motor, Gas turbine

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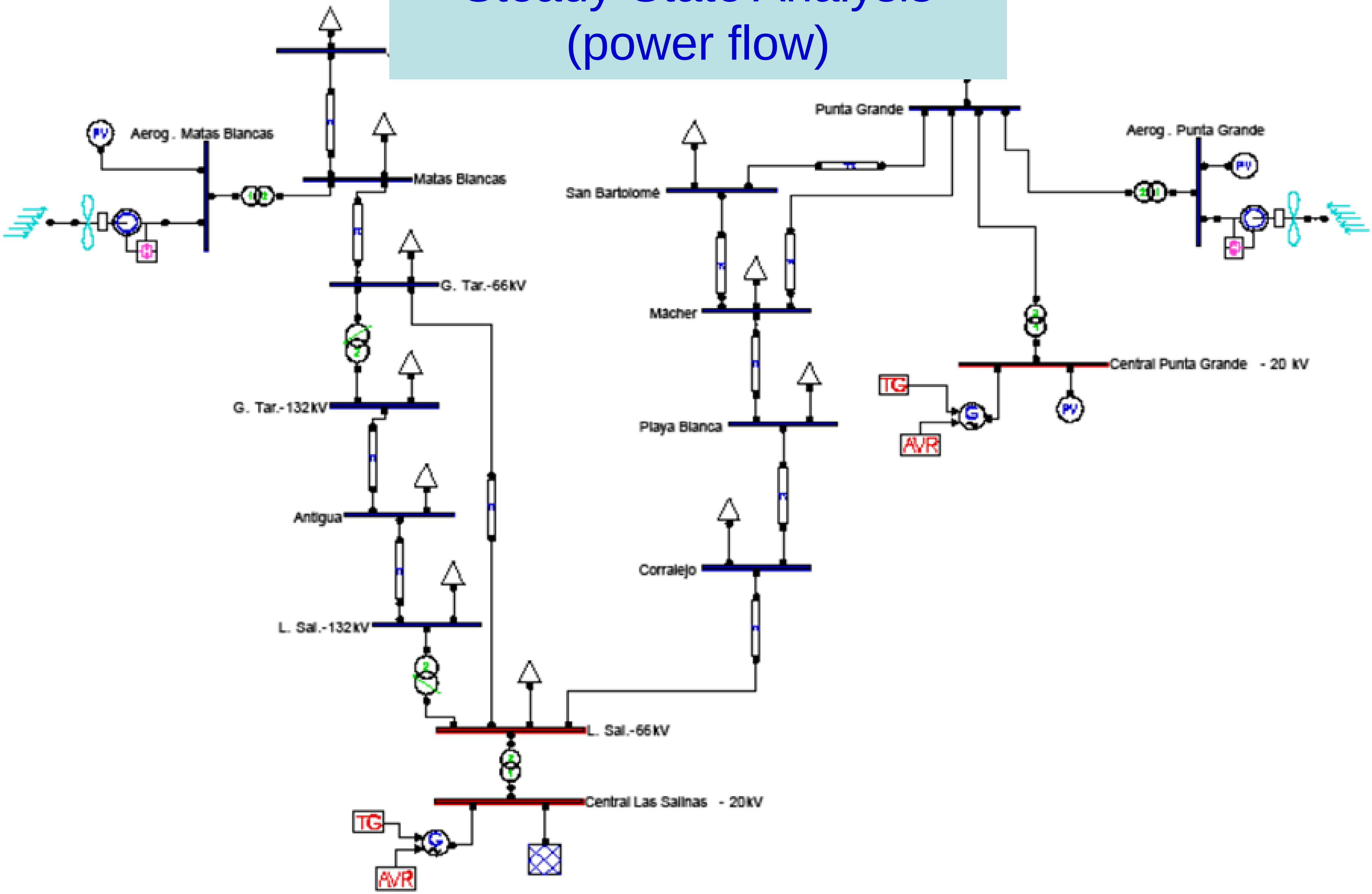
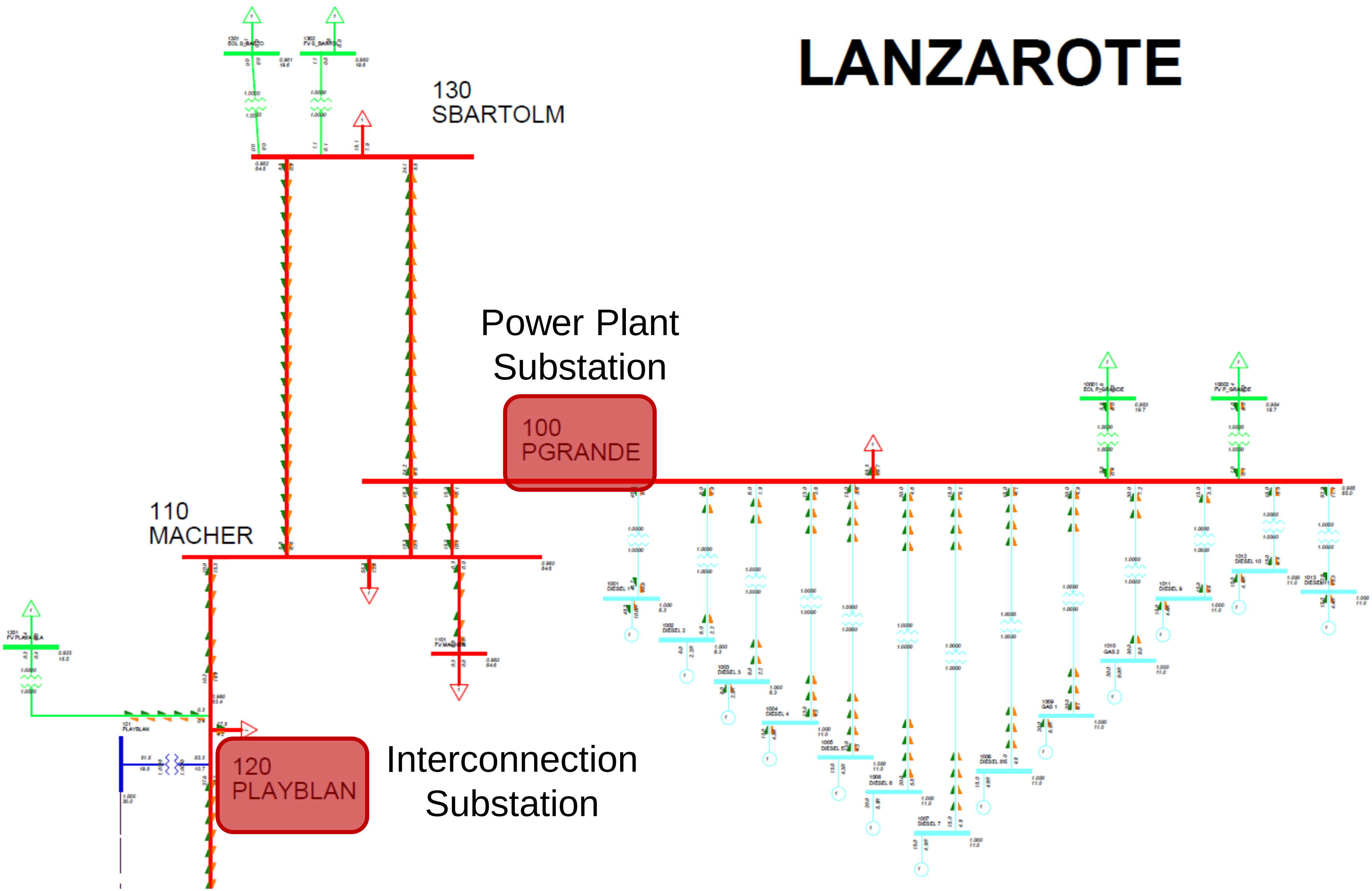
CASE STUDY 1: Fuerteventura - Lanzarote PSAT model

Steady-State Analysis (power flow)

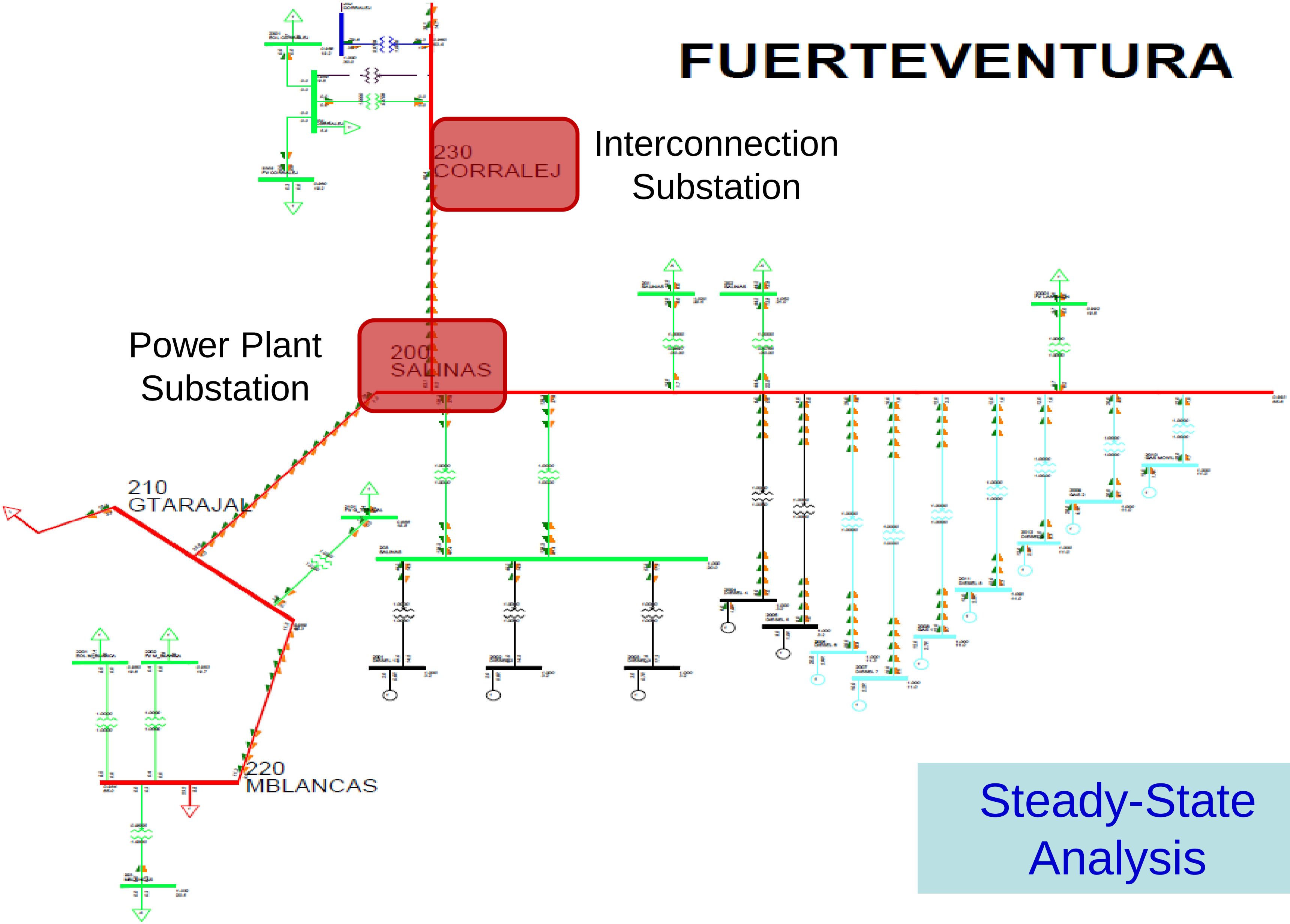


CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

Steady-State Analysis



CASE STUDY 1: Fuerteventura - Lanzarote PSSE model



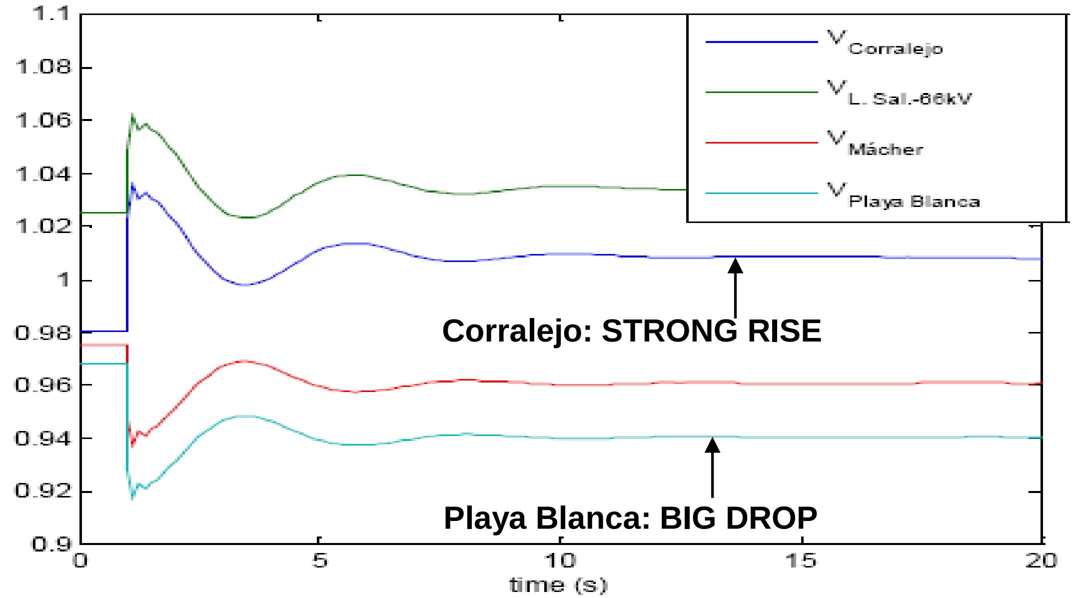
Steady-State Analysis

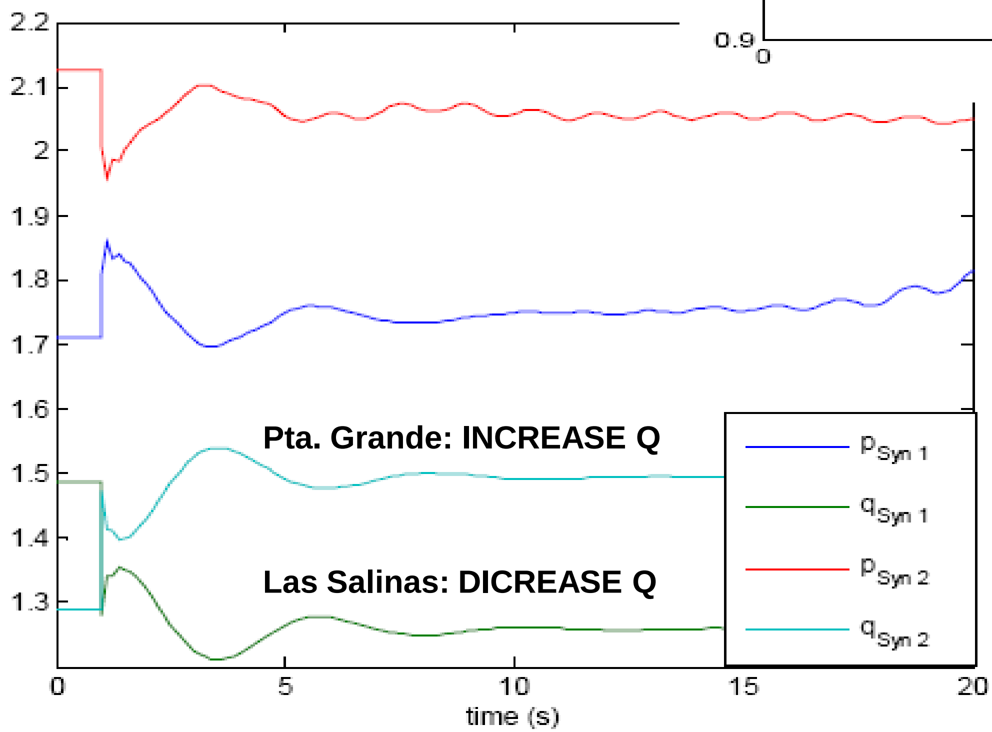
CASE STUDY 1: Fuerteventura - Lanzarote PSAT model

Dynamic Analysis

EVALUATION OF CONTINGENCIES →

Break out of the connection line between islands





SUBSTATIONS:

Corralejo - Playa Blanca (66 kV)

POWER PLANTS:

- Punta Grande (Lanzarote)
- Las Salinas (Fuerteventura)

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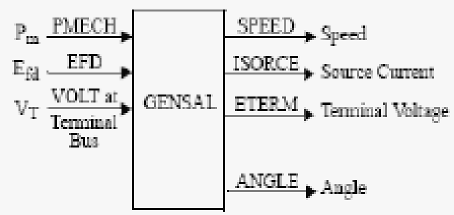
CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

Conventional generation units model

Modelo de alternador de Polos salientes

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

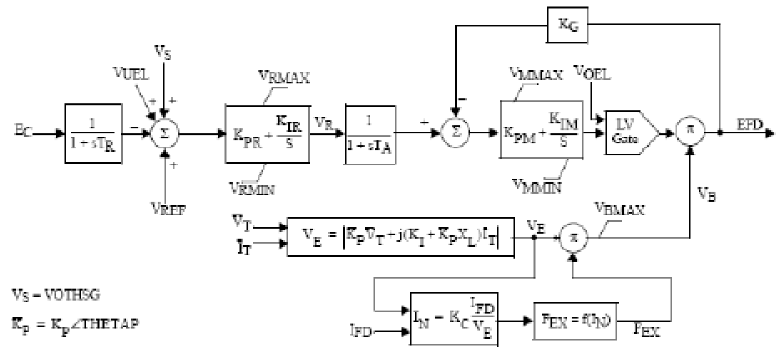
This model is located at system bus #______ IBUS,
machine #______ I,
This model uses CONs starting with #______ J,
and STATEs starting with #______ K.
The machine MVA is _________ for each of units = _________ MBASE.
ZSORCE for this machine is _________ + j _________ on the above MBASE.

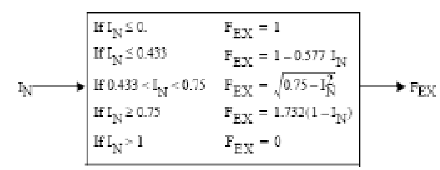


CONs	#	Value	Description
J			T'_{do} (>0) (sec)
J+1			T''_{do} (>0) (sec)
J+2			T''_{qo} (>0) (sec)
J+3			Inertia, H
J+4			Speed damping, D
J+5			X_d
J+6			X_q
J+7			X'_d
J+8			$X''_d = X''_q$
J+9			X_l
J+10			S(1.0)
J+11			S(1.2)

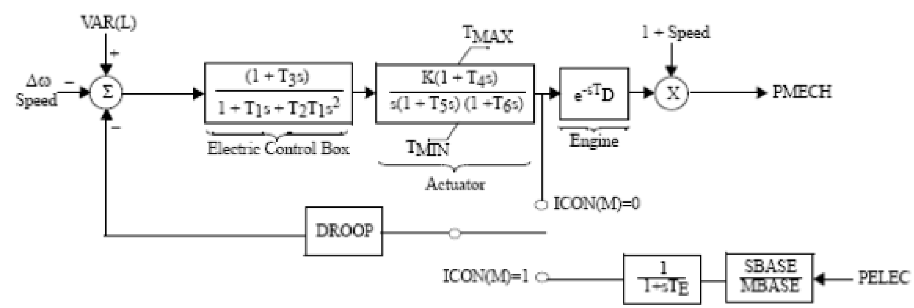
Note: X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

Modelo de excitación y regulador de tensión





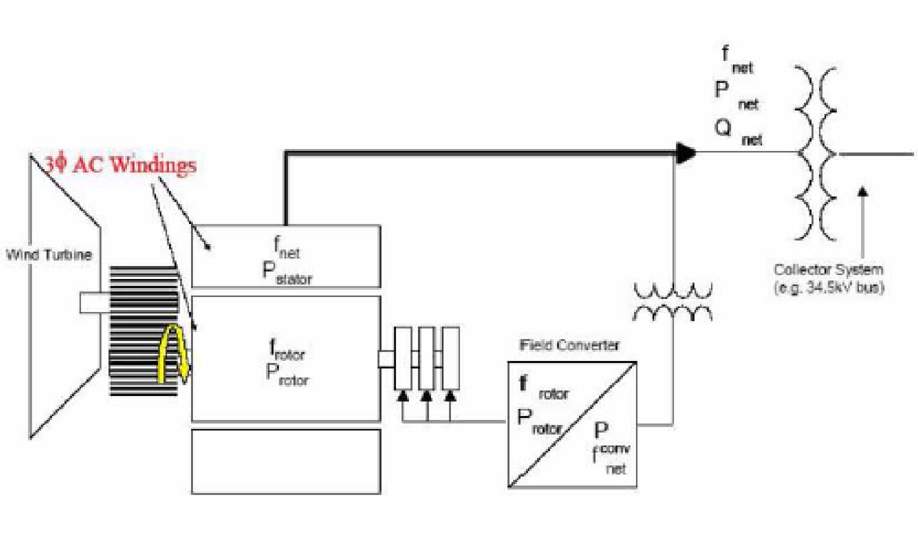
Modelo de regulador de velocidad de grupo diesel



CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

Wind generation system model

Diagrama genérico aerogenerador



Modelo de turbina eólica

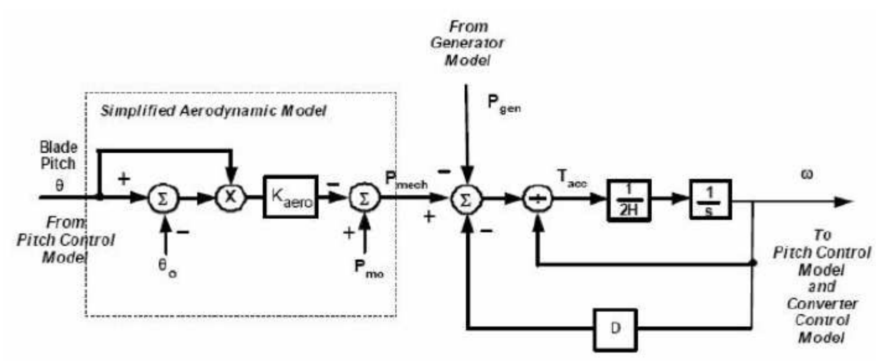
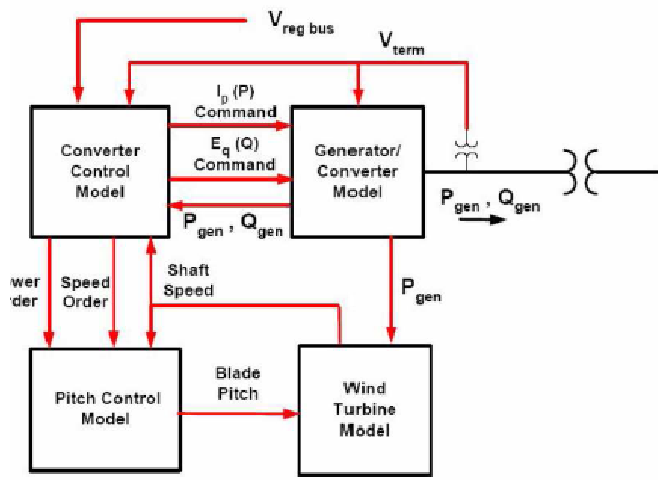
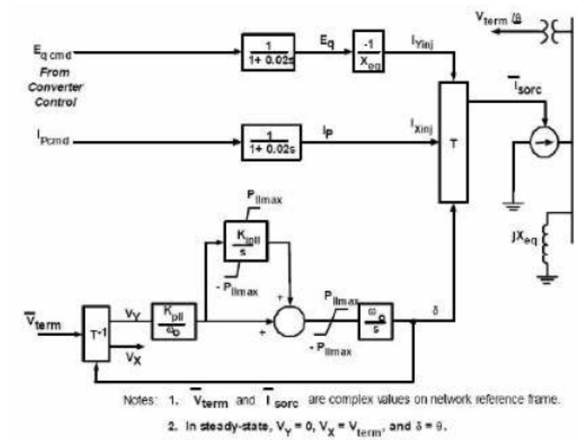


Diagrama de bloques de aerogenerador



Modelo de Generador/convertidor



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CASE STUDY 1: Fuerteventura - Lanzarote energy balance

WIND ENERGY LIMITATION:

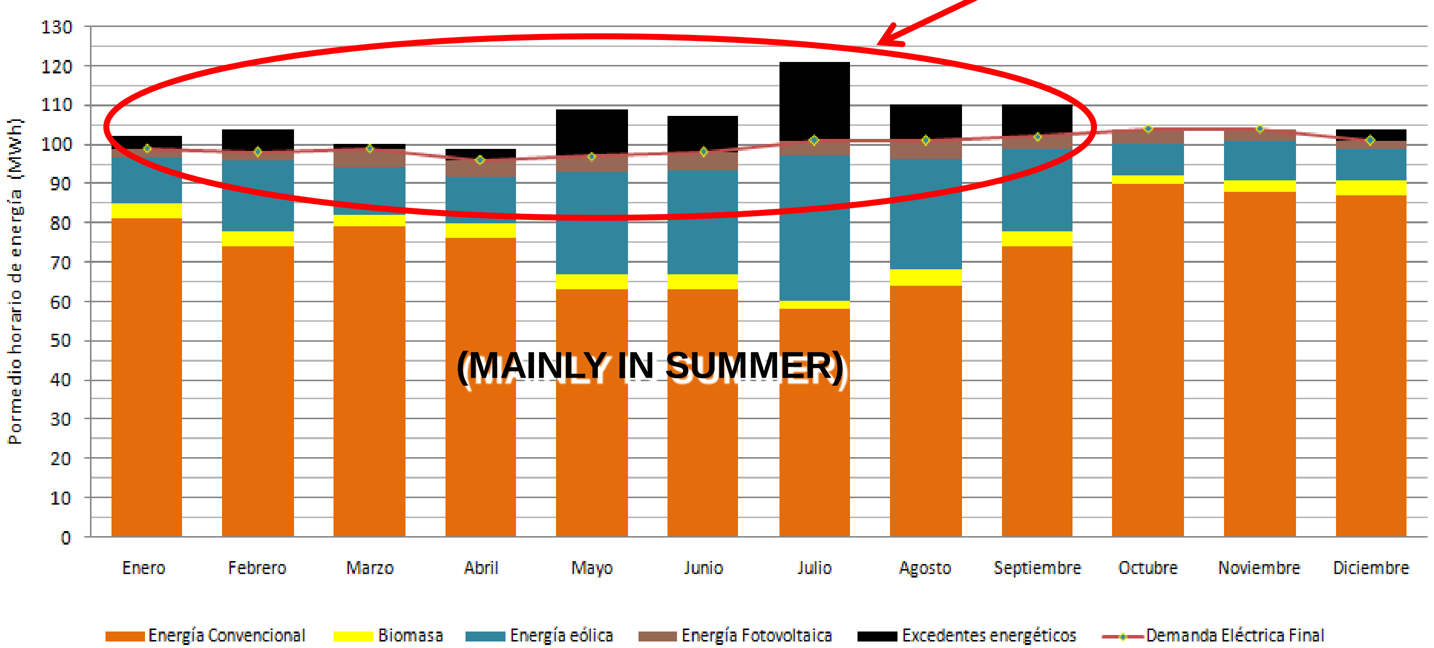
BALANCE FOR LANZAROTE ISLAND (2017)	
DEMAND	878,7 GWh
CONVENTIONAL GENERATION	223 MW
TOTAL RES (PV+WIND) (**WIND POWER**)	106 MW (**78 MW**)

SPANISH CODES: P.O 3.7 SEIE

5.2.5 Excedentes de generación no integrables en el Sistema.–En determinadas circunstancias, en las que se presente una demanda inferior a la prevista y/o una producción de las unidades objeto de este procedimiento superior a las previsiones realizadas anteriormente, el Operador del Sistema podrá precisar reducir la producción de la generación objeto del presente procedimiento.

Para ello se tendrá en cuenta la tecnología de cada una de las unidades de producción, con objeto de minimizar la modificación de generación necesaria.

TOTAL WIND ENERGY LIMITATION UP TO 19%



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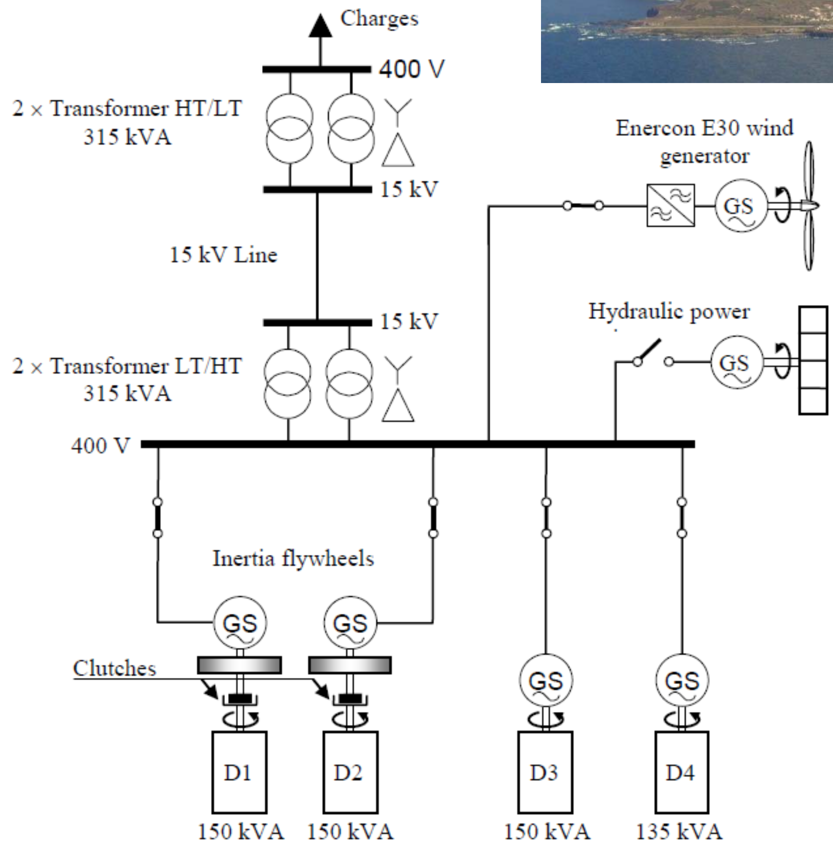
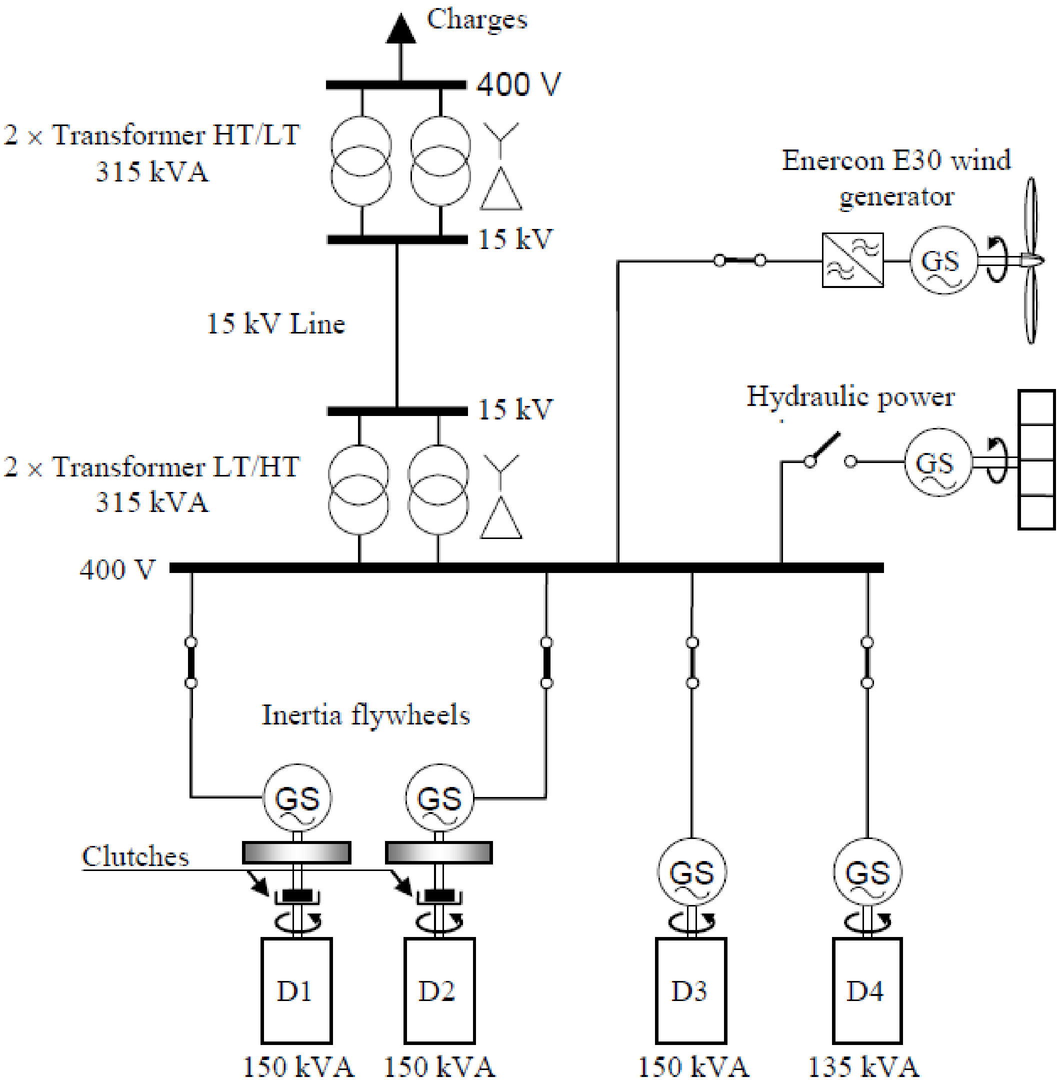
SQUEME OF THE SYSTEM:



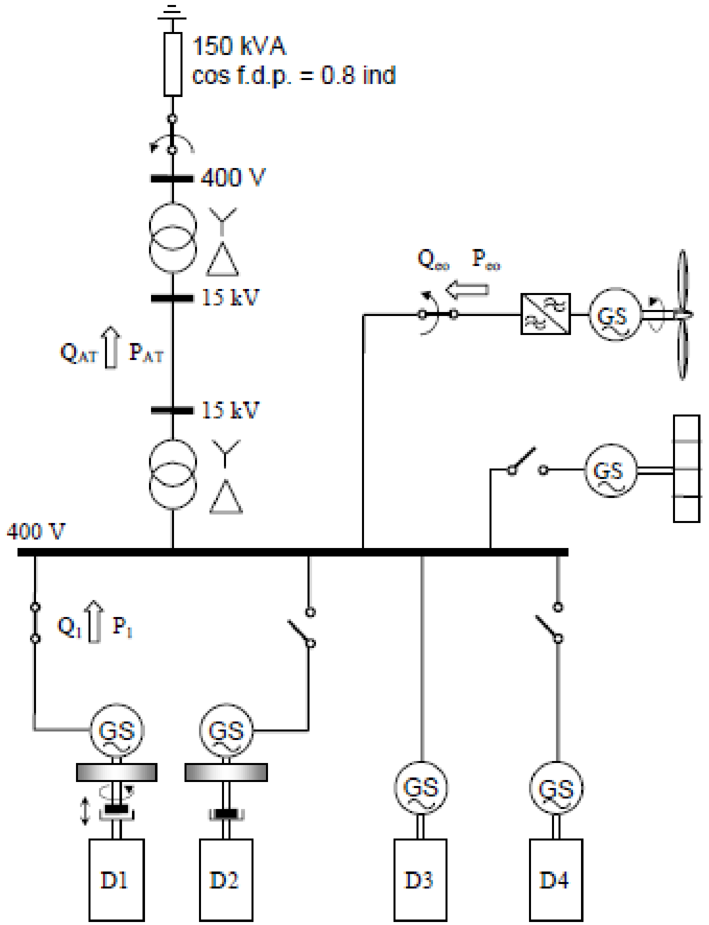
PROPOSED SYSTEM OPERATION→ DIESSEL / WIND / MIXED



- Diesel power units, three of 150 kVA and one of 135 kVA
- Inertia flywheels in two of the power units of 150 kVA
- 1 wind generator of 300 kW, variable speed and blade pitch control
- Transport line of 15kV, 600 m
- 2 boosting transformers of 400V/15kV
- 2 step-down transformers of 15kV/400V

CASE STUDY 2: Corvo Island

EXAMPLE OF DYNAMIC STUDY: Functioning of the power station is studied with variations of charge and generation in the **wind mode** with only one inertia flywheel



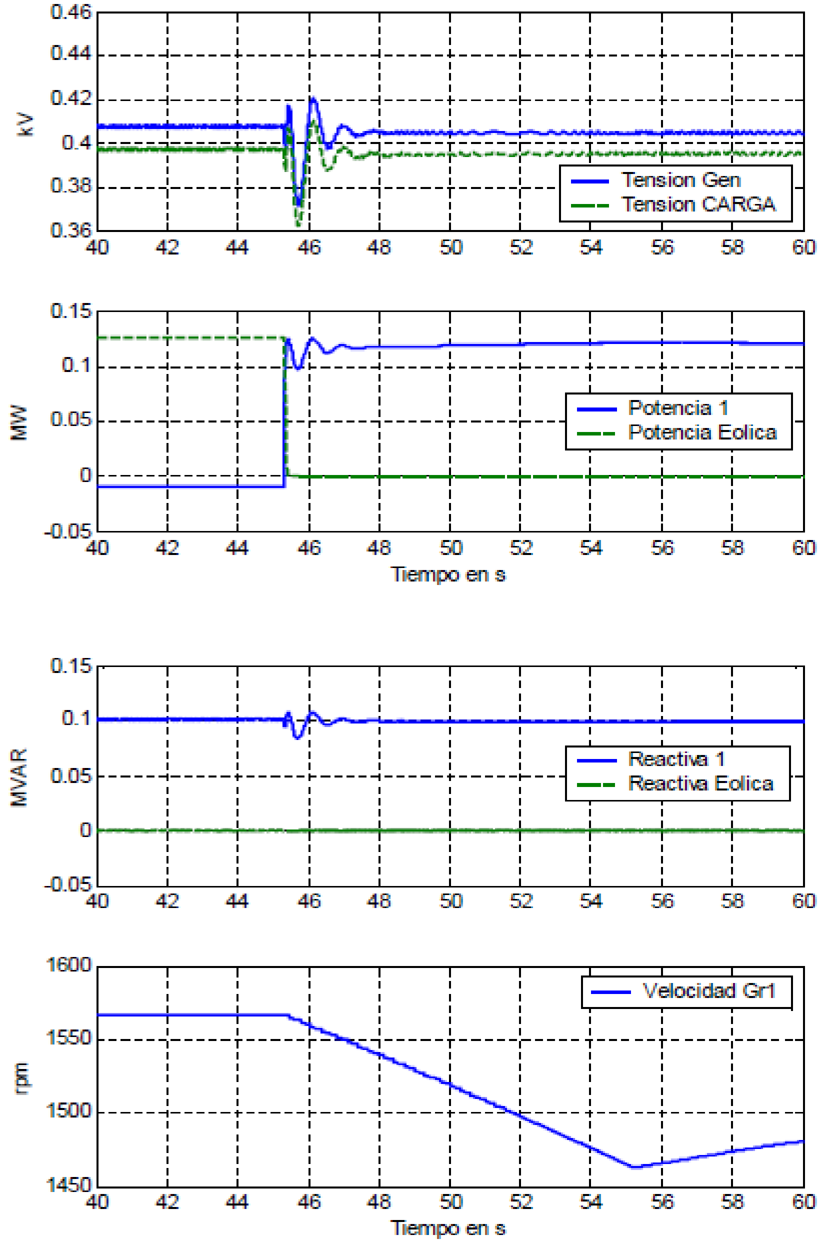
INITIAL CONDITIONS:

- Powered at a charge of 150 kVA with an inductive power factor of 0.8
- It is connected to the synchronous generator (with its corresponding flywheel) with the diesel motor uncoupled.
- The wind generator has sufficient wind to generate 160 kVA.
- The action of frequency control leads it to adjust to power the charge and maintain the frequency.

SIMULATIONS:

- Variation of the charge, where the disconnection is done at t ≈ 45 s and reconnection at t ≈ 55 s
- Disconnection of the wind generator, where the wind generator is disconnected at t ≈ 45 s

CASE STUDY 2: Corvo Island



EXAMPLE OF DYNAMIC STUDY:

Disconnection of the wind generator

CONCLUSION:

- In wind mode the most unfavorable situation comes from the disconnection of a charge
- The disconnection of the wind generator may cause the engaging of the diesel motor
- The strategy of control of the wind generator is decisive for the power station stability in the wind mode
- The contribution of the inertia flywheel in these situations is fundamental to guarantee a maintenance of frequency

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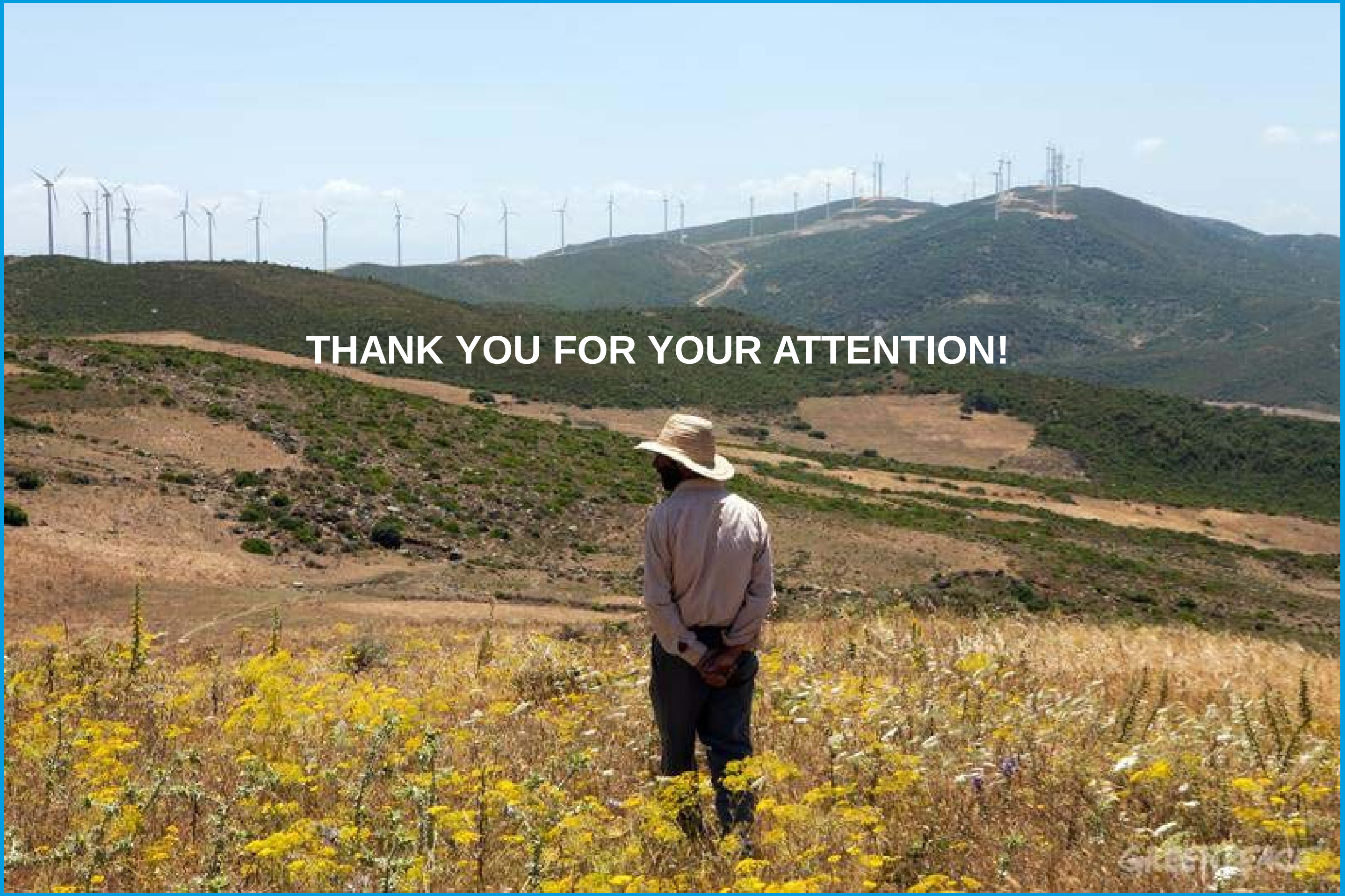

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