Electrical grid stability with high wind energy penetration

Fernando CASTELLANO HERNÁNDEZ
Head of Wind Energy Section
Renewable Energy Department
Canary Island Institute of Technology
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
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.
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
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
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 guarantee the viability of the electrical system balance

STABILITY STUDIES FOR PLANNING AND VERIFICATION
Balance between GENERATION and DEMAND

Power System Frequency

Demand and Generation vary continuously causing frequency to change

Frequency sets magnitude G & D
Absolute balance maintained
G=D

Generation varies
By inertia, response and instruction

Demand varies by consumer action
With some frequency sensitivity.
Some demand offers response control

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### Electric grid parameters and codes

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

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:

3 different INERTIA (H) of the hydraulic Pelton turbines

**Frequency of the system**
Reactive capacity regulation of wind energy converters (WEC):

Increase in grid renewable penetration $\rightarrow$ higher power control capacities
Electrical network: COMPLEMENTARY SERVICES

WEC power-frequency regulation:

Example for Power-Frequency Limitation

: "Static" Power-frequency control

Active power

Active power reserve

normal frequency

f_{low}  
f_{rated}  
f_{high}  
f_{max}
Electrical network: wind energy limitations and codes

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

Steady-State Analysis

NODAL STUDY

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

SYSTEM CAPACITY STUDY

- Conventional power plants units $\rightarrow$ 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
Grid studies methodology

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
Grid studies methodology

Voltage Dips (Sags)

- Point of start-up of the fault
- Fault in the transport network
- Duration of the fault
- Remove of the fault
- Fault in the second area
- Increase of the reactive power demand
- Reduction of the reactive power generation
- Deconnection due to over-speed area
- Demand/generation of reactive power from/to the “PCC”
- First area actuation of the protections (switch failure)
- Lost of wind generation
- DECONNECTION DUE TO OVER-SPEED AREA
- INCREASE OF THE REACTIVE POWER DEMAND
- REDUCTION OF THE REACTIVE POWER GENERATION
Grid studies methodology

Voltage Dips (Sags)

Active and reactive wind farm power during a voltage dip

- **Give Reactive** (Q+): Consume Reactive (Q-)
- **Give Active** (P+): Consume Active (P-)

**Active & Reactive Power**
- Blue ➔ P (W)
- Green ➔ Q (VA)
Grid studies methodology

Harmonic study

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

<table>
<thead>
<tr>
<th>Order</th>
<th>Harm. current [%]</th>
<th>Output power [kW]</th>
<th>Harm. current [%]</th>
<th>Output power [kW]</th>
<th>Harm. current [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comiente armónica</td>
<td>Potencia producida</td>
<td>Comiente armónica</td>
<td>Potencia producida</td>
<td>Comiente armónica</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>0.11</td>
<td>21</td>
<td>546</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>0.10</td>
<td>12</td>
<td>1300</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>0.17</td>
<td>13</td>
<td>230</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>0.14</td>
<td>14</td>
<td>259</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>0.21</td>
<td>15</td>
<td>318</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>0.11</td>
<td>16</td>
<td>1295</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>0.47</td>
<td>17</td>
<td>295</td>
<td>27</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>0.15</td>
<td>18</td>
<td>544</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>19</td>
<td>0.10</td>
<td>19</td>
<td>1239</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>1295</td>
<td>20</td>
<td>1295</td>
<td>30</td>
</tr>
</tbody>
</table>

Maximum total harmonic current distortion: [% of \( I_0 \)]

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

 Lantern: Power plants

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

INTERCONNECTION
66 kV Playa Blanca – Corralejo

LANZAROTE
PEAK OF THE DEMAND
170,30 MW

POWER PLANTS

FUERTEVENTURA
PEAK OF THE DEMAND
123,80 MW

LAS SALINAS
INSTALLED POWER: 187,43 MW
TECHNOLOGY: Diésel motor, Gas turbine
CASE STUDY 1: Fuerteventura - Lanzarote PSAT model

Steady-State Analysis (power flow)
CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

Steady-State Analysis

LANZAROTE

Power Plant Substation

130 SBARTOLM

110 MACHER

120 PLAYBLAN

Interconnection Substation
CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

FUERTEVENTURA

Interconnection Substation

Power Plant Substation

Steady-State Analysis
CASE STUDY 1: Fuerteventura - Lanzarote PSAT model

Dynamic Analysis

EVALUATION OF CONTINGENCIES

→ Break out of the connection line between islands

Pta. Grande: INCREASE Q
Las Salinas: DICREASE Q

Dynamic Analysis

Corralejo: STRONG RISE
Playa Blanca: BIG DROP

SUBSTATIONS:
Corralejo - Playa Blanca (66 kV)

POWER PLANTS:
• Punta Grande (Lanzarote)
• Las Salinas (Fuerteventura)
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, and STATES starting with #J, K.

The machine MVA is ________ for each of units = __________ on the above MBASE.

MVAR for this machine is ________ + j ________ on the above MBASE.

<table>
<thead>
<tr>
<th>CONS</th>
<th>#</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J+1</td>
<td></td>
<td>T_d0 (sec)</td>
<td></td>
</tr>
<tr>
<td>J+2</td>
<td></td>
<td>T_d0 (sec)</td>
<td></td>
</tr>
<tr>
<td>J+3</td>
<td></td>
<td>Inertia, H</td>
<td></td>
</tr>
<tr>
<td>J+4</td>
<td></td>
<td>Speed damping, D</td>
<td></td>
</tr>
<tr>
<td>J+5</td>
<td></td>
<td>X_d</td>
<td></td>
</tr>
<tr>
<td>J+6</td>
<td></td>
<td>X_d</td>
<td></td>
</tr>
<tr>
<td>J+7</td>
<td></td>
<td>X_d</td>
<td></td>
</tr>
<tr>
<td>J+8</td>
<td></td>
<td>X_d = X_d</td>
<td></td>
</tr>
<tr>
<td>J+9</td>
<td></td>
<td>X_d</td>
<td></td>
</tr>
<tr>
<td>J+10</td>
<td></td>
<td>S(1.0)</td>
<td></td>
</tr>
<tr>
<td>J+11</td>
<td></td>
<td>S(1.2)</td>
<td></td>
</tr>
</tbody>
</table>

Note: X_d, X_d, X_d, X_d, X_d, X_d, X_d, X_d, H, and D are in pu, machine MVA base.
CASE STUDY 1: Fuerteventura - Lanzarote PSSE model

Wind generation system model
## Case Study 1: Fuerteventura - Lanzarote Energy Balance

### Wind Energy Limitation:

**Balance for Lanzarote Island (2017)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>878.7 GWh</td>
</tr>
<tr>
<td>Conventional Generation</td>
<td>223 MW</td>
</tr>
<tr>
<td>Total RES (PV+Wind) (Wind Power)</td>
<td>106 MW</td>
</tr>
</tbody>
</table>

Total wind energy limitation up to 19% (mainly in summer).

**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 las unidades 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.
CASE STUDY 2: Corvo Island

SQUEME OF THE SYSTEM:
CASE STUDY 2: Corvo Island

PROPOSED SYSTEM OPERATION → DIESEL / 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
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 \( t \approx 45 \text{ s} \) and reconnection at \( t \approx 55 \text{ s} \)
- Disconnection of the wind generator, where the wind generator is disconnected at \( t \approx 45 \text{ s} \)
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
THANK YOU FOR YOUR ATTENTION!

Fernando CASTELLANO HERNÁNDEZ
fcastellano@itccanarias.org
www.itccanarias.org