WIND FOR SUSTAINABLE ENERGY FUTURE & CHALLENGES IN ITS GRID INTEGRATION

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Out of the 7+ billion world population, over 1.3 billion don’t have access to electricity due to technical, geographical and social reasons.
Among all these, wind is the fastest growing generation technology.
GLOBAL WIND INSTALLED CAPACITY

Global Wind Power Cumulative Capacity (Data: GWEC)

Source: Global Wind Energy Council
## WIND SHARE IN THE POWER SYSTEM

### World, as of June 2012

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>World wind energy share</td>
<td>254 GW</td>
</tr>
<tr>
<td>World wind energy growth rate</td>
<td>28%</td>
</tr>
<tr>
<td>Wind share in the World energy mix</td>
<td>2.5 %</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>20 - 25 %</td>
</tr>
</tbody>
</table>

### India, as of 31 Dec. 2012

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total power generation</td>
<td>210,952 MW</td>
</tr>
<tr>
<td>Captive generation</td>
<td>34,444 MW</td>
</tr>
<tr>
<td>Total generation capacity</td>
<td>245,396 MW</td>
</tr>
<tr>
<td>Wind installed capacity</td>
<td>18,420 MW</td>
</tr>
<tr>
<td>% Share of wind energy</td>
<td>7.5 %</td>
</tr>
</tbody>
</table>
According to the orientation of the axis of rotation with respect to the wind direction, wind turbines are classified as

- **Vertical-axis turbines (VAT)**
- **Horizontal-axis turbines (HAT)**

Vertical-axis WTGs are used only in small-scale installations.

Majority of modern WTGs are of horizontal-axis structure.
VERTICAL AXIS WIND TURBINE
WIND ENERGY CONVERSION SYSTEMS
Largest Wind Turbine in commercial use:
Enercon E126, 7.5 MW, rotor dia. 130 m, hub height: 135 m.
Power extracted by a wind turbine is:

\[ P_W = \frac{1}{2} \rho U_W^3 C_P (\lambda, \beta) \]

- \( \rho \) = Air density, kg/m\(^3\)
- \( A \) = Rotor sweep area, m\(^2\)
- \( U_W \) = Wind speed, m/s
- \( C_P \) = Performance coefficient

Theoretical limit of \( C_P \): 59.3%  (Betz limit)

The power in the wind is proportional to:

- The cube of wind speed ⇒ (proportional to tower height)
- Size of the rotor ⇒ (swept area)
- The air density ⇒ (affected by temperature, location)
Variable speed WTGs can capture wind energy more efficiently as compared to fixed speed WTGs.

However, due to variable frequency output, they require power electronic converters for interfacing the machine with the system.
High capacity wind turbines use 3 phase AC generators of the following types for energy conversion:

<table>
<thead>
<tr>
<th>Asynchronous Generator (Induction Generator)</th>
<th>Synchronous Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Squirrel-Cage Rotor (SC)</td>
<td>● with Variable Excitation</td>
</tr>
<tr>
<td>● Wound-Rotor (WR)</td>
<td>● with Permanent Magnet Excitation</td>
</tr>
<tr>
<td>● Doubly-Fed (DF)</td>
<td></td>
</tr>
</tbody>
</table>
WIND ENERGY CONVERSION PROCESS

1. Wind
2. Aerodynamics
3. Gearbox
4. Generator
5. Converter
6. Transformer
7. Power System
Based on the generator systems used, wind turbines are classified into four types:

- **Type A**: Fixed Speed
- **Type B**: Limited Variable Speed
- **Type C**: Variable Speed with Partial Scale Energy Converter
- **Type D**: Variable Speed with Full Scale Energy Converter
WIND ENERGY CONVERSION SYSTEMS

Type A: Fixed Speed

Type B: Limited Variable Speed

Type C: Variable Speed with Partial Scale Converter

Type D: Variable Speed with Full Scale Converter
CHALLENGES IN GRID INTEGRATION OF WIND ENERGY
Wind energy is a technology of variable and intermittent output, with very little controllability and dispatchability.

When wind energy is considered for increasing the generation capacity or displacing of aged thermal units, can we get the same kind of controllability from WTGs as that of conventional generators..?
**THE NEED FOR ENERGY BALANCE**

Frequency deviation from the nominal value represents mismatch between the active power (MW) generation and consumption.

Voltage deviation from the nominal value represents mismatch between the reactive power (MVAR) generation and consumption.
- Turbine provides the active or real power (P).
- Governor is used to regulate the real power output.
- Exciter provides the reactive or imaginary power (Q).
- AVR is used to regulate the reactive power output.
Conventional synchronous generator based units possess few abilities which are extremely important in controlling the grid frequency. These are:

- Inertial response
- Speed droop characteristic with increase in load
- Limited short-term overloading capability
The relationship between generation, load and frequency change in the power system can be related as

\[ \frac{df}{dt} = \frac{P_G - P_L}{2H} \]

where \( H = \frac{1}{2} \frac{\omega_m^2}{MVA} \) known as Inertia Constant [s]

From the above, it follows that large system inertia decreases the frequency deviation following a power imbalance.

- Inertia constant of thermal units: 3 - 8 s
- Inertia constant of Wind generators: 2 - 6 s
Increasing share of wind energy will reduce the effective inertia of the system due to power electronic coupling.

The entire power system will then behave as a lighter system.

A lighter system will experience larger changes in the frequency even for small mismatches in the supply and demand.
Droop allows multiple generators to be operated in parallel to share common loads proportional to their rating.

Droop parameter \( (R) \) is defined as

\[
% R = \frac{\Delta f}{\Delta P} \times 100
\]
Increasing wind penetration in the electrical system increases the equivalent droop of the system.

For a 20% renewable penetration, the conventional generating capacity will reduce to $100/120 = 83.33\%$ or $0.8333$ pu.

The effective droop of the system increases to $\frac{R}{0.833} = 1.2 \, R$, where $R$ is the initial value of droop.

Means, only $83.33\%$ generating resources participate in frequency regulation.
a) No wind energy penetration, equivalent system droop = 100%

b) 20% wind, conventional system has reduced to $\frac{100}{120} = 83.33\%$

c) Equivalent system droop is $\frac{1}{0.8333} = 120\%$ of original
EFFECT OF INCREASED DROOP

- Higher droop means less responsive system to load changes.
- This results in more frequency deviations after load changes.
- To reduce this adverse impact, WTGs must respond to frequency changes as in the case of conventional units.

\[ \Delta P_1 > \Delta P_2 > \Delta P_3 \]
NEED FOR POWER MARGIN

- For any generating unit to be used for frequency control, availability of sufficient reserve generation capacity is a vital requirement.

- This reserve capacity (known as primary control reserve) is intended to limit the immediate fall in frequency after a load event.

- In systems where generation capacity is surplus, reserve margin is created by part load operation of units.

- During low frequency periods, this reserve margin will be used to meet the increased demand.
Conventional units provide system frequency support in the form of inertial response, primary response and secondary response.

Primary response (Governor response) establishes active power balance within 30 – 40 s.

Secondary response (AGC action) modifies active power set point of units so that primary control reserve is replenished in 20 – 30 m.
WTGs INERTIAL RESPONSE

**Fixed Speed WTGs**
- Uses cage rotor induction generator.
- Due to direct electrical coupling between stator winding and the grid, these machines provide Inertial Response.
- But response is sluggish as compared to synchronous generator.

**Variable Speed WTGs**
- Uses DFIG and PM Synchronous Generator.
- Connection with the grid is through power electronic converters.
- DFIG (uses partial converter): Very little Inertial Response.
- PMSG (uses full converter): No Inertial Response.
For grid connection, the WTGs should be able to provide 100% VAR if the voltage at the PCC decreases to 0.15 pu.

WTGs should not be isolated from grid during fault in the system.
CURRENT RESEARCH
Variable speed WTGs can be used for frequency regulation by introducing inertial and droop effects artificially. For this, two control loops are needed,

one acting on the rate of change of frequency (df/dt) and
the other acting on the frequency deviation (Δf).
Power margin needed for participating in frequency regulation can be created by method known as deloading.
For using wind energy systems for sustainable energy future, these machines must have capabilities similar to synchronous machines:

- Low voltage fault ride through
- Wide frequency and voltage range of operation
- Ability to provide frequency and voltage response

With the new machine technologies and control philosophies, most of these requirements are being achieved gradually.

Thus, the target of 20% wind in total generation mix by 2030 could be realized without much difficulty.
Thank you

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