Assessment of the Mexican Interconnected Electric Power System Operation considering Non-Conventional Renewable Energies

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Grid integration

- In recent years, several WFs have been installed in the Mexican system, especially in the Southeastern (SE) portion of the system (2.5 GW) ~4% of total current installed generation
- Wind farm output is transmitted to the bulk transmission system via two 400 kV lines with SVC voltage support
- Other significant wind projects are being planned (3.9GW) including large solar PV farms
The installed level of wind generation has increased significantly over the last decade.

At present there is over 2250 MW of installed capacity in the SE system; by contrast, the total peak demand in the SE system is about 3200 MW.

Local generation includes four large hydro plants accounting for about 5 GW of installed capacity.

Hydro reserves used to respond to fast wind and load fluctuations.

<table>
<thead>
<tr>
<th>Area</th>
<th>No. of WFs</th>
<th>Installed capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeastern</td>
<td>24</td>
<td>2250</td>
</tr>
<tr>
<td>Western</td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>Northwestern</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Northeastern</td>
<td>2</td>
<td>75</td>
</tr>
<tr>
<td>Northern</td>
<td>1</td>
<td>225</td>
</tr>
</tbody>
</table>
Operational challenges

- Wind power spatial distribution
- Wind power intermittency – wind power fluctuations ranging from 0 to about 100 MW within an hour
- Size relative to hydrogeneration in the SE system - AGC and active hydro power control must correct the random fluctuations in both wind and load
- Large scale wind integration results in reduced hydro generation, low inertia, and low fault levels
Advanced monitoring of system behavior

- Measurement-based techniques designed to supplement system information
- Emphasis on the use of real-time data fusion techniques

$$\hat{X} = a_o(t)\psi_o^T + \cdots + a_d(t)\psi_d^T + \sum_{j=d+1}^{m} a_j(t)\psi_j^T$$

**Dynamic trajectories**

- Dimensionality reduction
- Feature extraction
- Visualization,
- …

$$X_{wind} = \begin{bmatrix} x_1(t_1) & \cdots & x_1(t_N) \\ \vdots & \ddots & \vdots \\ x_m(t_1) & \cdots & x_m(t_N) \end{bmatrix}$$
Spatio-temporal representation

a) Temporal evolution

b) Spatial distribution

c) Clustering
Short-term wind generation forecasting

- Owing to its stochastic nature, each wind power time-series is represented by an unobserved component model

\[ x(t) = T(t) + \sum_{j=1}^{p} A_j(t) \cos \phi_j(t) \]

Stochastic trend \hspace{1cm} Harmonic model

- Random walk plus noise model in the context of Kalman filtering
Dynamic impact of wind energy

- **Rigorous analytical models** of 7 geographical regions – 635 generators, 25 SVCs, and 26 WFs
- Written models of WFs including active power control and inertial support
- **Objective** - Define limits of integration and advanced control actions
- Studies show quasilinear frequency-generation loss behavior for low penetration levels
Impact on oscillatory stability

- WFs tend to form clusters of coherent machines for various contingency events
- WFs in the north and south systems tend to swing in opposition
- The analysis of phase relationships cannot be studied using small-signal analysis techniques
- Damping computed using nonlinear modal identification techniques
Transient frequency behavior

- Integration of large levels of wind may result in under-voltage, under-real power generation and then over-frequency.
- Of concern, simulation studies show the presence of frequency overshoot by as much as 10%, but the rise does not exceed the AGC upper threshold.
- Since the frequency drops below the first under frequency load shedding set point, about 1550 MW of firm load needs to be shed for cases with triple and quadruple contingencies.
- Reduction of system inertia results in lower post-contingency voltages below the acceptable range of system behavior – requires higher levels of active (reactive) power.

a) Without wind

b) With wind – 3100 MW

AGC threshold

c) Effect on voltage
Long-term frequency behavior

- Approaches based on the notion of Center-of-Gravity (COG) – local and global frequency behavior
- The system is divided into $n$ coherent areas - a local Center of Inertia (COI) is associated with each area
- Fast simulation of area COIs without performing a transient stability – Frequency sensitivities

$$
\Delta f_j(t) = \frac{\partial f_j}{\partial f_{COl_i}} \Delta f_{COG}(t)
$$
Impact on torsional dynamics

- Three-machine detailed EMTP-type dynamic equivalent for the wind farms -
- The study seeks to perform a coupled analysis of SSR response and SSTI of DFIG with SVC controls and nearby series-compensated transmission lines.
- Modal analysis results reveal two dominant, undamped modes at frequencies 30.30 Hz, 28.37 Hz in close agreement with small-signal stability results
- The local SVC is seen to strongly affect torsional behaviour
THANK YOU